

Fundamental Concepts of Chemistry – Part 2

September 14th, 2016

Yesterday, we covered:

- Matter, atoms, elements;
 - Rules governing significant figures;
 - Avogadro's number and the mole;
 - Molar mass;
 - Mass-mole-number and mass-mole-atom conversions
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- **Chapter 1, section 1.1 to section 1.5**

Today's class:

- Solutions;
 - Writing chemical equations;
 - Stoichiometry;
 - Yields of chemical reactions;
 - Limiting reactants;
 - Redox reactions (if time permits)
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- **Chapter 1, sections 1.6 – sections 1.10; Chapter 9.1; Chapter 17, sections 1 and 2**

What is a solution?

- What do the following three photos have in common?



Solutions

- **Solutions:** homogenous mixture of two or more substances
- All solutions contain a solute and the solvent:
 - **Solvent:** the main medium, or the largest quantity
 - **Solute:** the pure substance dissolved in the solvent
- Solution can exist in different phases, do not necessarily have to be a liquid

Solvent determines the phase of a solution

- **Phase:** any of the three states of matter: liquid, solid, or gas

Solvent Type	Solute Type		
	Gas	Liquid	Solid
Gas	Diving gas (He, O ₂)	Humid air (N ₂ , O ₂ , H ₂ O)	Air above I ₂ (N ₂ , O ₂ , I ₂)
Liquid	Carbonated water (H ₂ O, CO ₂)	Vodka (H ₂ O, C ₂ H ₅ OH)	Saline solution (H ₂ O, NaCl)
Solid	H ₂ storage alloy (La, Ni, H ₂)	Plastic (PVC, dioctylphthalate)	Steel (Fe, C, Mn)

Aqueous solutions are the most common

- If water is used as the solvent, the solution is called **aqueous**
- If we have a solution, we need to be able to determine the quantity of **solute** in the given quantity of **solvent**
- Why do we need to know the quantity of **solute** in a given **solvent**?

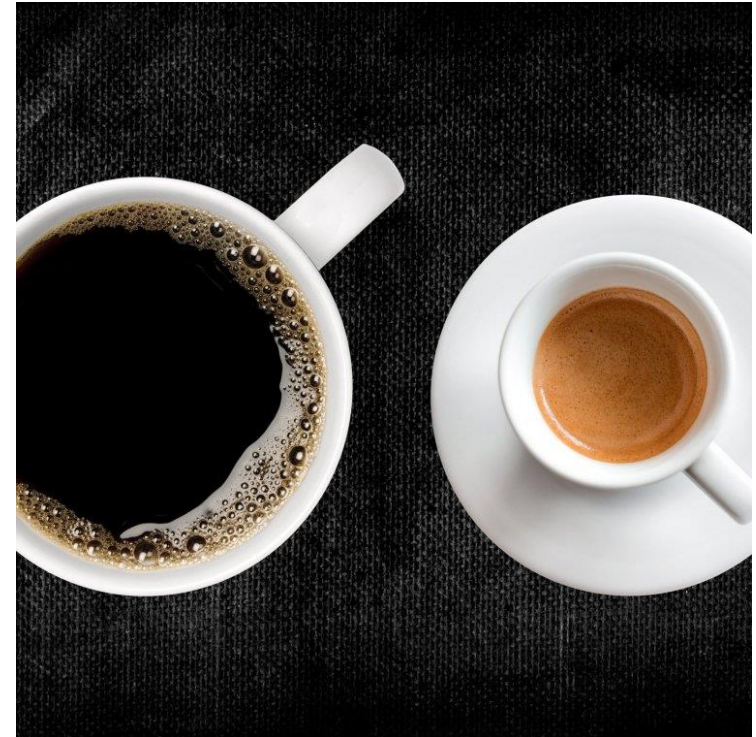
Carbon steel

- Steel is an alloy of iron (Fe), carbon (C), and other elements.
- Iron is the **solvent** and carbon is the **solute**



Solution concentration

- **Concentration:** the amount of a solute dissolved in a given quantity of solvent
- A **concentrated** solution has a large amount of solute
- A **dilute** solution has a small amount of solute



Methods to calculate solution concentration

- **Mass Percent:**

$$\text{Mass percent} = \frac{\text{Mass of solute}}{\text{Mass of solution}} \times 100\%$$

- **Molarity:**

$$\text{Molarity (M)} = \frac{\text{Moles of solute (n}_{\text{solute}})}{\text{Volume of solution (V}_{\text{solution}})}$$

- **Mole fraction:**

$$\text{Mole Fraction (X}_A) = \frac{\text{Moles of solute (n}_A)}{\text{Total moles of solution (n}_{\text{total}})}$$

Molality

- If the temperature of a solution is **increased**, the concentration of a solution will change

- **Molality (b):**

$$\text{Molality } (b) = \frac{\text{Moles of solute } (n_{\text{solute}})}{\text{Mass of solvent } (m_{\text{solvent}})}$$

- Therefore, molality is independent of temperature

Concentration conversions

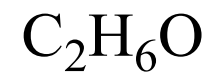
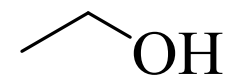
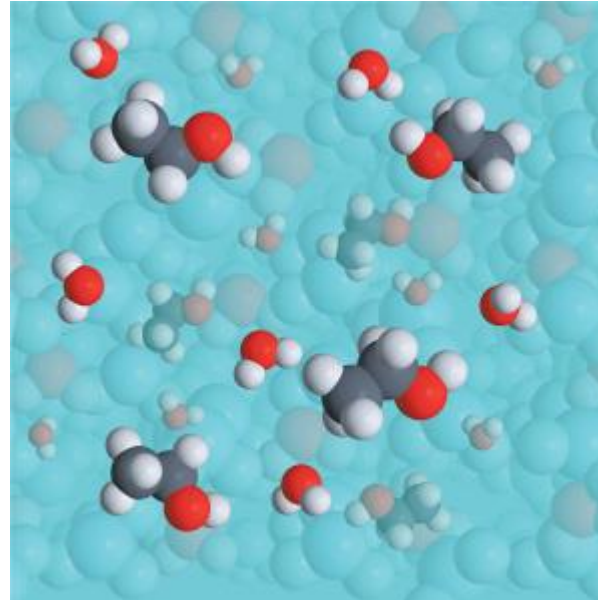
- Need to be able to convert between mole fraction, molarity, and molality
- To convert between mole-based concentration measures, need to relate to mass.
- **Density:**

$$\text{Density } (\rho) = \frac{\text{Mass (m)}}{\text{Volume (V)}}$$

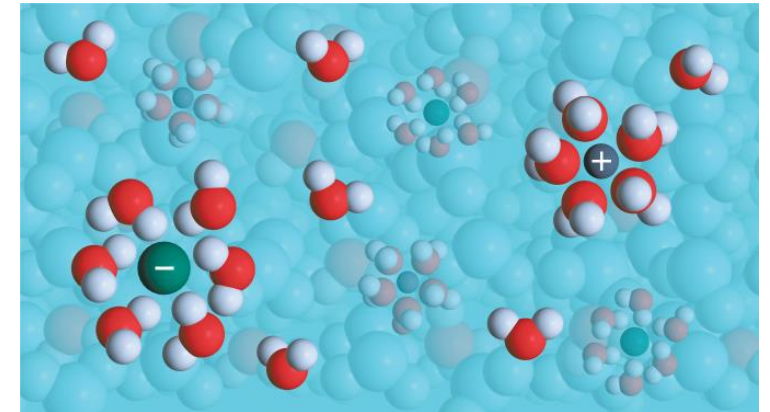


Species in aqueous solutions

- When we are working with solutions, we need to think on both a **macroscopic** and **microscopic** level
- Solutions that contain **ionic species** tend to conduct electricity



Ethanol



Sodium chloride

The concentration of ionic solutions

- For **non-ionic solutions**, we can calculate the concentration by simply applying the molarity equation.

$$\text{Molarity (M)} = \frac{\text{Moles of solute (n}_{\text{solute}})}{\text{Volume of solution (V}_{\text{solution}})}$$

- For **ionic solutions**, we may be required to calculate the concentration of individual ionic species.

The concentration of ionic solutions

- The ratio of ionic species in solution is determined by the chemical formula:

1 mole ammonium nitrate (NH_4NO_3) = 1 mole ammonium (NH_4^+) and 1 mole nitrate (NO_3^-)

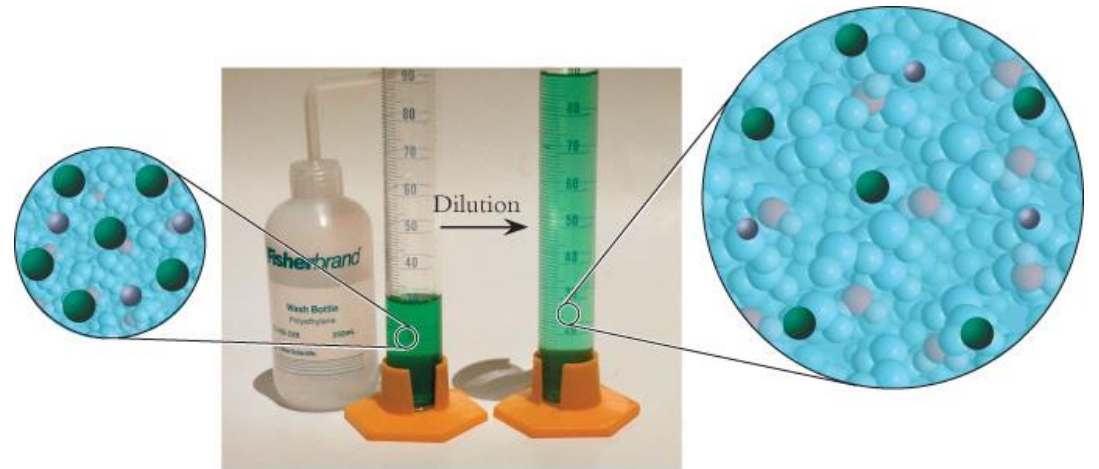
1 M ammonium nitrate (NH_4NO_3) = 1 M ammonium (NH_4^+) and 1 M nitrate (NO_3^-)

1 M NaCl_2 = 1 M Na^+ and 2M Cl^-

- Knowing the **molarity ratio** of an ionic species will help determine the concentration of individual ionic species in solution

How do you dilute a concentrated solution?

- **Dilution:** solute concentration remains the same but the volume of the solvent changes
- The number of moles of a solute do not change:



Courtesy of John Olmsted

$$n_{\text{before dilution (initial)}} = n_{\text{after dilution (after)}}$$

How do you dilute a concentrated solution?

- We know that the number of moles (n) does not change:

$$n_{\text{before dilution (initial)}} = n_{\text{after dilution (after)}}$$

- We also know that the concentration of a solution is:

$$\text{Molarity (M)} = \frac{\text{Moles of solute (}n_{\text{solute}}\text{)}}{\text{Volume of solution (}V_{\text{solution}}\text{)}}$$

How do you dilute a concentrated solution?

- We can re-arrange the concentration equations to be equal to the moles in a solution:

$$M = \frac{n}{V} \longrightarrow n = (M) \times (V)$$

- Set the n_{initial} equal to the n_{final} , to obtain:

$$(M_{\text{initial}}) \times (V_{\text{initial}}) = (M_{\text{final}}) \times (V_{\text{final}})$$

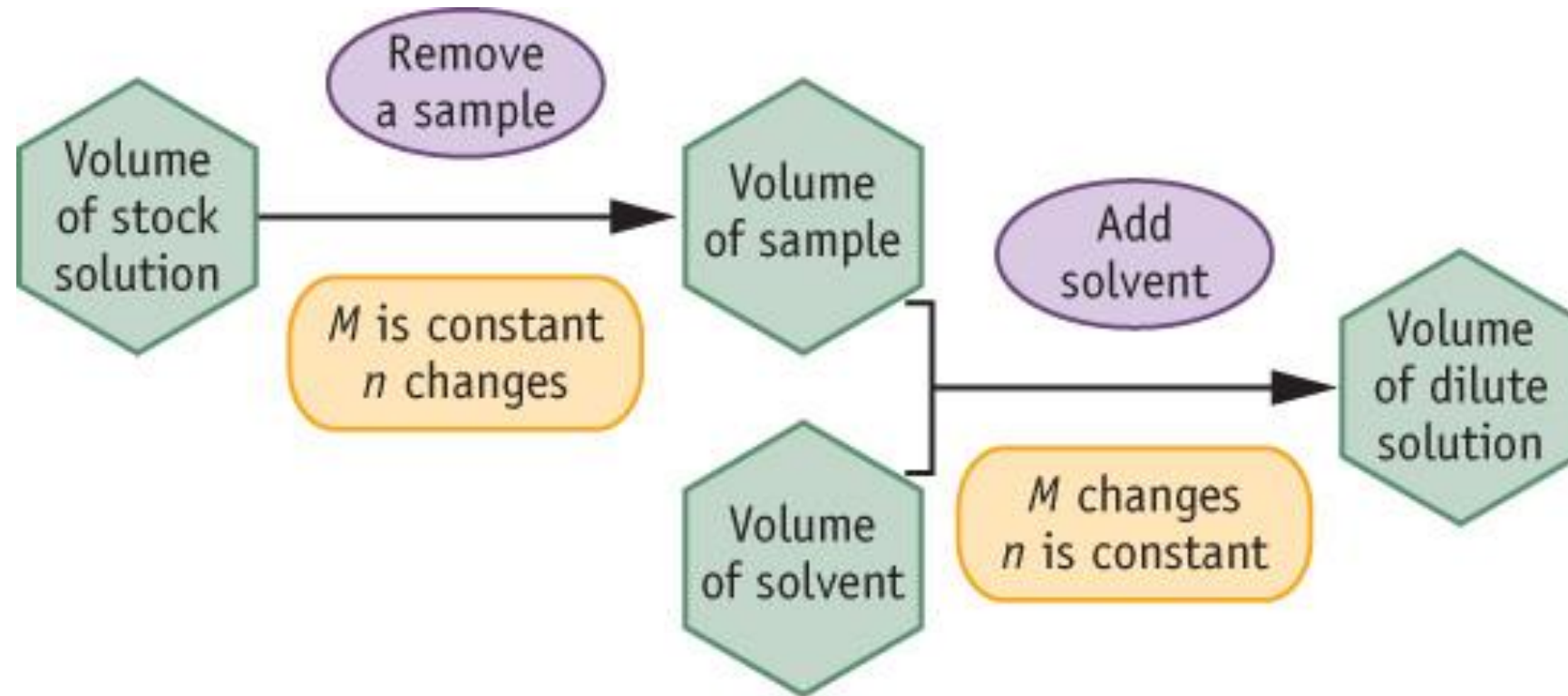
Dilutions of a species

- The previous relationship is often seen as:

$$C_1V_1 = C_2V_2$$

- Where:
 - C_1 = Molarity (mol/L), initial
 - V_1 = Volume (L), initial
 - C_2 = Molarity (mol/L), final
 - V_2 = Volume (L), final

Dilution flowchart



Chemical equations and stoichiometry

- Chemical equations are fundamental to visualizing chemical reactions
- Haber-Bosch process produces ammonia from nitrogen and hydrogen
- There are set guidelines when writing balanced chemical reactions



How to write a (balanced) chemical reaction

- Firstly, the amount of each element is always conserved (**conservation of mass**)
- Secondly, the overall electrical charge must also be conserved
- **Reagents:** species that take part in the reaction
 - **Reactants:** species that are consumed during the reaction
- **Products:** species that are produced during a reaction

How to write a (balanced) chemical reaction

- **Guideline #1:**
 - Reactants appear on the left of the reaction arrow, the products on the right of the reaction arrow
- **Guideline #2:**
 - The **stoichiometric coefficient** must be placed before the chemical formula for each reagent
- **Guideline #3:**
 - Stoichiometric coefficients must be the smallest integers that give a balanced equation
- **Guideline #4**
 - Charge is always conserved!

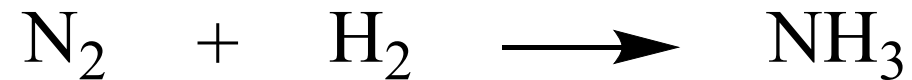
How to write a (balanced) chemical reaction

- Guideline #1:
 - Reactants appear on the left of the reaction arrow, the products on the right of the reaction arrow

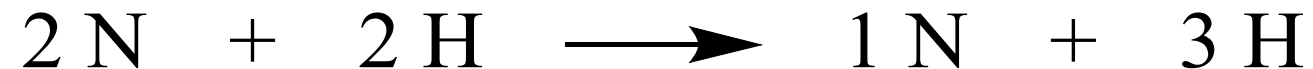


How to write a (balanced) chemical reaction

- Guideline #2:
 - The **stoichiometric coefficient** must be placed before the chemical formula for each reagent

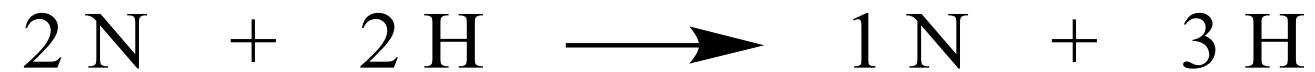


- **First** need to balance the chemical reaction
 - Pull apart the chemical reaction into individual elements

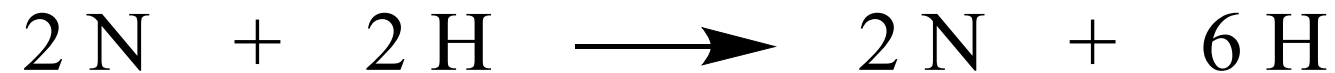


How to write a (balanced) chemical reaction

- Once the equation is pulled apart, need to add balance the number of elements on each side of the equation.
 - Start with one element at a time (nitrogen)

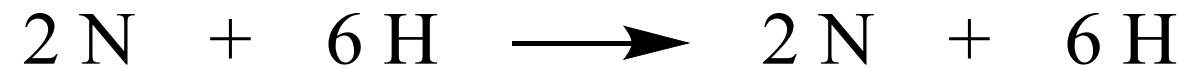


- Need to increase the “product” nitrogen by 1, which increases the number of product nitrogens (1 mole of NH_3 there are 1 mole of N and 3 mole H):

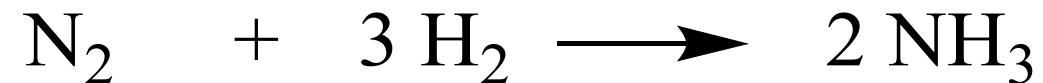


How to write a (balanced) chemical reaction

- Balance the number of hydrogens by increasing the reactant hydrogens by 4:



- Finally, reassemble the chemical equation:

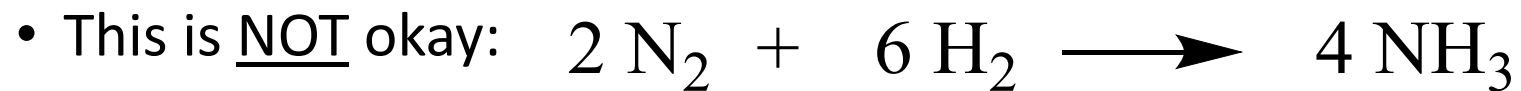
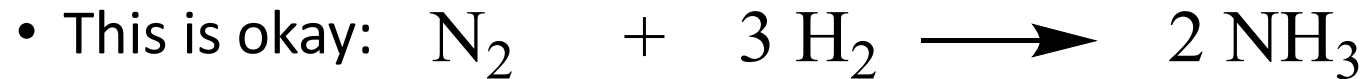


- This is now a balanced chemical reaction!!

How to write a (balanced) chemical reaction

- Guideline #3:

- Stoichiometric coefficients must be the smallest integers that give a balance equation:



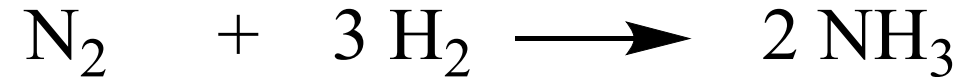
Stoichiometry of chemical equations

- **Stoichiometry:** the relationship between the amounts of substances undergoing reactions
- Chemical reactions has help us determine **how much** of a specific substance is formed or consumed in a chemical reaction
- Most importantly:

Can now relate reactants to products using stoichiometric coefficients!

Haber-botsch reaction and stoichiometry

- An industrial engineer wants to figure out how much ammonia she will be able to produce if she uses 68 grams of nitrogen.



- We will use this as an example to discuss **stoichiometric ratio**, **percent yield**, and **limiting reagents**, and **table of amounts**

Let's move on to doing the Haber-Bosch practice problem!