Stoichiometry
(adapted from Dr. Maxwell’s Handout)

The topic of stoichiometry deals with relating quantities of reactants and products. The word stoichiometry comes from the Greek word stoicheion meaning “element” and metron meaning “measure,” and that basically tells us what we’re going to be doing in this chapter -- dealing with measurements of elements, more specifically, dealing with quantities of reactants and products in chemical reactions. Stoichiometry is basically chemical arithmetic. This topic is one of the pinnacles of general chemistry, and also one of the topics we expect you to have learned in high school chemistry. You will be tested on this topic throughout the term! Mastery of this topic requires mastery of topics like naming, writing formulas, writing and balancing equations, and using molar mass, density, mass and volume in dimensional analysis calculations. This topic will also carry through or continue to be important throughout this term and all the terms of chemistry you take. This topic is not hard, but requires patience and lots of practice. The Cal Poly philosophy of “learn by doing” really applies here, so again, I must emphasize the importance of doing lots and lots of problems. I’ll try to make this topic more interesting by using examples that apply to the real-world, because stoichiometric relationships are involved in everything. Below are some guidelines to supplement your text reading and lecture notes, and some examples for you to practice on. Keep these sheets handy while working on problems.

The Basics:

1. You first need to be able to recognize a stoichiometric problem. The problems can be very basic stoichiometric problems, which relate mass amounts to mole or molecule amounts. For example:

   How many moles of aspirin (C₉H₈O₄) are in a tablet containing 500 mg of aspirin?

   In more involved stoichiometric problems, you’ll be asked to relate a quantity of one of the products or reactants in a reaction to a quantity of one of the other products or reactants. For example:

   How many moles of hydrochloric acid are needed to completely neutralize 25 grams of solid sodium hydroxide?

   There are clues in each of these examples that tell you these are stoichiometry problems. The phrases “how many moles” and “how many grams” are your first clues, and then the fact that these quantities are being related to other quantities are the rest of the clues. So what are you given? What are you being asked to solve for?

2. With rare exception, you will need a correctly written and balanced chemical equation. The coefficients in front of reactants and products are needed to determine the quantitative relationships between products and reactants. The equation may be given to you, but you may have to translate a word statement into a correct chemical equation and then balance it. You cannot write a proper chemical reaction without the necessary knowledge of correct chemical nomenclature -- so practice these skills if you’ve had trouble with them in the past.

3. With rare exception, you will need to determine the number of moles of the substance that is given in the problem. Moles are the measurement unit of the chemist, the link between atomic scale and macroscopic scale! You can get to moles via a number of routes:

   a. You could actually be given moles in the statement of the problem

   b. You could be given grams of the pure substance, in which case you determine the molar mass and use that in the following manner:

   \[
   25 \text{ g of NaOH} \times \frac{1 \text{ mole NaOH}}{40.00 \text{ g NaOH}} = \text{________________ moles NaOH}
   \]
c. You could be given the number of atoms or molecules of a substance, in which case you'd use Avogadro's number, as in the following example

\[
3.0 \times 10^{23} \text{ molecules CO}_2 \times \frac{1 \text{ mole CO}_2}{6.022 \times 10^{23} \text{ molecules CO}_2} = \frac{\text{mole CO}_2}{\text{mole CO}_2}
\]

d. You could be given the volume and the density of a pure liquid or solid, and then with that and knowledge of molar mass, you can get to moles, as in the following example:

\[
25.0 \text{ mL Br}_2 \times \frac{3.103 \text{ g Br}_2}{1 \text{ mL Br}_2} \times \frac{1 \text{ mole Br}_2}{159.8 \text{ g Br}_2} = \frac{\text{moles Br}_2}{\text{moles Br}_2}
\]

e. You could be given the volume of a solution and its concentration, in the concentration unit we'll use the most: Molarity (M), which is moles of solute per liter of solution. So for example, how many moles of HCl are in 2.0 L of 0.500 M HCl?

\[
\frac{0.500 \text{ moles HCl}}{1 \text{ L}} \times 2.0 \text{ L} = \frac{\text{moles HCl}}{\text{moles HCl}}
\]

f. As you can see in Chapter 5 with the Ideal Gas Law, if you have the pressure, temperature, and volume of an ideal gas, we can determine the number of moles of that gas. (i.e., \(PV = nRT\) can be rearranged to solve for \(n\)).

4. And finally, there will usually be a key conversion factor that comes from the balanced equation.

So let's do some more examples to practice. I think you'll find it helpful to write complete units on all terms:

A. You spill 2.00 moles of HCl on the floor, how many moles of sodium hydroxide will be required to exactly neutralize (or react with) it?

First, start out with a balanced equation: \(\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}\)

Next, what is the ratio between moles HCl and moles NaOH according to this equation? This is your key conversion factor in this problem! This factor comes from the relationship expressed by the balanced chemical equation. Next, use what is given and this conversion factor to solve the problem:

\[
2.00 \text{ moles HCl} \times \frac{1 \text{ mole NaOH}}{1 \text{ mole HCl}} = 2.00 \text{ moles NaOH}
\]

B. Your turn: You spill 4.00 moles of phosphoric acid on the floor, how many moles of sodium hydroxide will be required to completely neutralize (or react with) it?

First, start out with a balanced equation: ____________________________

Next, what is the ratio between moles phosphoric acid and moles NaOH according to this equation?

Next, use what is given and this conversion factor to solve the problem:
C. Aqueous sodium hypochlorite (NaOCl), best known as household bleach, is prepared by reaction of sodium hydroxide with chlorine. Aqueous sodium chloride and water are also formed. i. How many grams of sodium hydroxide are required to react with 25.0 g of chlorine? ii. How many grams of sodium hypochlorite will be produced?

i. First, start out with a balanced equation:

\[
2 \text{NaOH (aq)} + \text{Cl}_2 (g) \rightarrow \text{NaOCl (aq)} + \text{NaCl (aq)} + \text{H}_2\text{O (l)}
\]

Next, what is the ratio between moles sodium hypochlorite and chlorine?  \(\frac{2 \text{ moles NaOH}}{1 \text{ mole Cl}_2}\)

Use this conversion factor and others needed to go from what is given to what is asked for:

\[
25.0 \text{ g Cl}_2 \times \frac{1 \text{ mole Cl}_2}{70.90 \text{ g Cl}_2} \times \frac{2 \text{ moles NaOH}}{1 \text{ mole Cl}_2} \times \frac{40.00 \text{ g NaOH}}{1 \text{ mole NaOH}} = 28.2 \text{ g NaOCl}
\]

ii. We already have our balanced equations, so what is the ratio between moles sodium hypochlorite and chlorine? \(\frac{1 \text{ moles NaOCl}}{1 \text{ mole Cl}_2}\)

Use this conversion factor and others needed to go from what is given to what is asked for:

\[
25.0 \text{ g Cl}_2 \times \frac{1 \text{ mole Cl}_2}{70.90 \text{ g Cl}_2} \times \frac{1 \text{ moles NaOCl}}{1 \text{ mole Cl}_2} \times \frac{74.44 \text{ g NaOCl}}{1 \text{ mole NaOCl}} = 26.2 \text{ g NaOCl}
\]

D. Your turn: A common reaction of many metals is to form the corresponding metal oxide when burned in air. Burning magnesium in air (oxygen!) produces magnesium oxide. If you burn 25.0 g of magnesium in an excess of oxygen, how many grams of magnesium oxide will form?

First, start out with a balanced equation: ________________________________

Next, what is the ratio between moles magnesium and moles magnesium oxide according to this equation?

Next, use what is given and this conversion factor to solve the problem: