Name ____ Hour ________

CHM CON B Unit 12 Packet: Stoichiometry

Learning Goals:

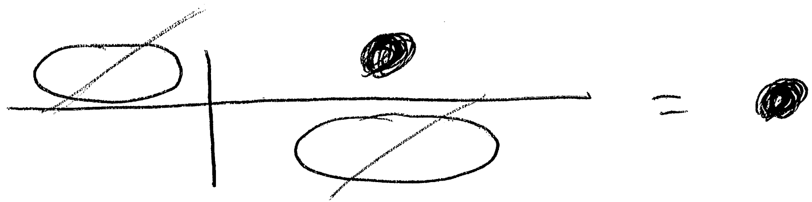
1. I can calculate the **moles** of a compound produced given the **mass** of one reactant.
2. I can calculate the **mass** of a compound produced given the **mass** of one reactant.
3. I can calculate the **mass** of a compound produced given the **moles** of one reactant.
4. I can calculate the **moles** of a compound produced given the **moles** of one reactant.
5. I can identify the limiting and excess reagent when given the masses two reactants and calculate the amount of product.
6. I can calculate the amount of heat produced for a given mass of reactant from a balanced chemical equation.

VOCABULARY (I can define/describe the following terms in my own words)

- excess reactant
- limiting reactant
- molar enthalpy of reaction
- stoichiometric factor

Stoichiometry of Shapes

(1)



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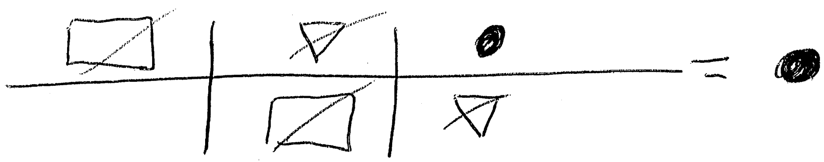

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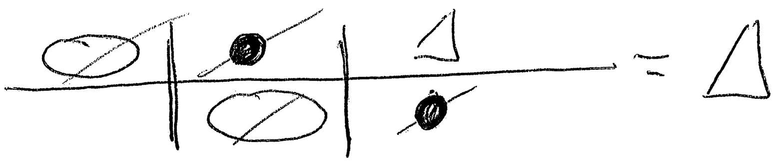

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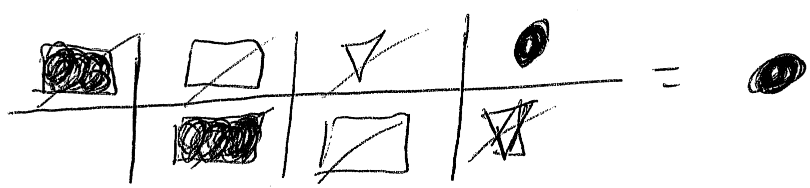

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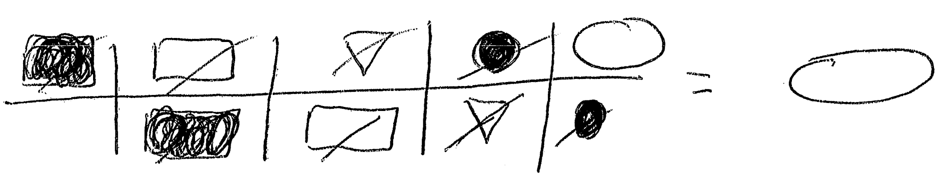


Stoichiometry Introduction

Let's consider the balanced reaction equation between hexane and oxygen gas to form carbon dioxide and water:

$$2\ C_6H_{14} + 19\ O_2 \rightarrow 12\ CO_2 + 14\ H_2O$$

What we need to do here is ask ourselves exactly what this equation tells us. First of all, we know that the equation is balanced since there are the same numbers of each type of atom on each side of the equation. In balancing the equation, we manipulated the number of molecules on each side of the arrow. Hence, the coefficients depict the number of molecules involved in the reaction. **So, in the reaction above, 2 molecules of C_6H_{14} react with 19 molecules of O_2 to form 12 molecules of CO_2 and 14 molecules of H_2O.**

It is doubtful that dealing with molecules directly in calculations would ever be convenient since molecules are so incredibly small. However, since one mole of any compound has the same number of molecules (6.02×10^{23}), the number of molecules in a sample is directly proportional to the number of moles present in that sample. *Because of this, the* coefficients *in a balanced chemical equation also depict the number of* moles *involved.* **Hence, the above balanced equation also tells us that 2 moles of C_6H_{14} react with 19 moles of O_2 to form 12 moles of CO_2 and 14 moles of H_2O.** Units of mass or volume (g or mL) CANNOT be directly substituted into this statement since 1 g or 1 mL of two different substances do not necessarily contain the same number of molecules.

So, given a balanced chemical equation, we are able to determine the mole relationship between any two components of that equation with respect to the reaction involved. Hence, a balanced chemical equation enables us to determine the number of moles of one reactant that will react with a given number of moles of another reactant. Likewise, we can determine the number of moles of a reactant which would be required to produce a given number of moles of a product. Essentially, we can determine the relationship between any two substances in a balanced chemical equation in terms of moles.

Solving problems based upon balanced chemical equations is a topic called stoichiometry (pronounced "stoy key om it tree"). The mathematical process used in solving stoichiometry problems of this type involves dimensional analysis. The central dimensional factor for stoichiometry is based upon the corresponding balanced chemical equation and we will call this the *stoichiometric factor*. Stoichiometric factors have mole units in BOTH the numerator and the denominator. The difference between numerator and denominator lies in the substance involved. The numbers for the numerator and denominator are taken from the balanced chemical equation. Namely, the corresponding coefficients from the balanced chemical equation represent the number of moles involved. Which chemical species is in the numerator and which is in the denominator of the stoichiometric factor depends on what is required for unit cancellation

Let's again return to the balanced chemical equation:

$$2\ C_6H_{14} + 19\ O_2 \rightarrow 12\ CO_2 + 14\ H_2O$$

Some possible stoichiometric factors which we could use from this equation are

$$\frac{2\text{ moles } C_6H_{14}}{19\text{ moles } O_2} \qquad \frac{19\text{ moles } O_2}{2\text{ moles } C_6H_{14}} \qquad \frac{19\text{ moles } O_2}{14\text{ moles } H_2O} \qquad \frac{2\text{ moles } C_6H_{14}}{12\text{ moles } CO_2} \qquad \frac{12\text{ moles } CO_2}{14\text{ moles } H_2O}$$

Again, **the numbers in front of the mole figures in these stoichiometric factors are merely the corresponding coefficients from the balanced chemical equation.** To use a factor derived from the chemical equation, we make sure the substances involved are those, which are expressed in the problem. The "starting" data substance will be in the denominator of this "mole-to-mole" factor and the "answer" will be in the numerator to allow for cancelation of units.

Example Problem 1: Determine the number of moles of O_2 that will completely react with 30.0 moles of C_6H_{14} in the reaction above.

The "starting" data species is C_6H_{14} and so this will be in the denominator *of the stoichiometric (mole-to-mole) factor. The answer sought involves O_2, so this will be in the* numerator*. Again the numbers for this factor come from the balanced chemical equation.*

$$\frac{30.0 \text{ moles } C_6H_{14}}{} \times \frac{19 \text{ moles } O_2}{2 \text{ moles } C_6H_{14}} = 285 \text{ moles of } O_2$$

Note that we not only indicate the mole *units in the stoichiometry problem above, but we also indicate the* Substances *involved for each mole unit. This is* important *in stoichiometry since the units otherwise would easily become confused.*

Now it's your turn.

Practice Problem 1: Continue to use the same reaction as above: $2\ C_6H_{14} + 19\ O_2 \rightarrow 12\ CO_2 + 14\ H_2O$. Carry out the calculations to determine the necessary quantities. Set the work for your problem up as show in the example above.

1. Calculate the number of moles of CO_2 produced from the complete reaction of 7.30 moles of C_6H_{14}.

$$\frac{7.30 \text{ mol } C_6H_{14}}{} \times \frac{12 \text{ moles } CO_2}{2 \text{ mol } C_6H_{14}} = 73.8 \text{ mol } CO_2$$

2. Calculate the number of moles of O_2 required to make 9.35 moles of water.

$$\frac{9.35 \text{ mol } H_2O}{} \times \frac{19 \text{ mol } O_2}{14 \text{ mol } H_2O} = 12.69 \text{ mol } O_2$$

Our work above in using moles to do stoichiometry problems is really nice but we seldom, if ever, would measure moles directly in the laboratory. A very common way to express an amount of material is to give its mass in grams. However, moles of different substances would have different masses in grams. Since stoichiometry works only on a mole-to-mole basis, masses in grams would have to be CONVERTED to moles before we could use the stoichiometric ratio which deals exclusively with moles. If the answer is sought in grams, the mole figure from the stoichiometric ratio would have to be converted to grams for the substance involved.

To convert between grams and moles or moles and grams in stoichiometry problems obviously requires using the Molecular weights (aka formula masses, molar masses) of the substances involved. Of course, a balanced chemical equation is also needed to determine the stoichiometry mole-to-mole conversion factor. Let's use this next question to review equation balancing and calculating molecular weights.

Review Problem 1: Balance the following chemical reaction equation.

$$\underline{2}\ HNO_3 + \underline{1}\ Ba(OH)_2 \rightarrow \underline{1}\ Ba(NO_3)_2 + \underline{2}\ H_2O$$

Review Problem 2: Find the molar masses for the following compounds to the nearest 0.01 g/mol.

1. Nitric acid, HNO_3

   $1(1.01) + 14.01 + 3(16)$

   63.02 g/mol HNO_3

2. Barium nitrate, $Ba(NO_3)_2$

   $1(137.33) + 2(14.01) + 6(16)$

   261.35 g/mol $Ba(NO_3)_2$

3. Barium hydroxide, $Ba(OH)_2$

   $1(137.33) + 2(16) + 2(1.01)$

   171.35 g/mol $Ba(OH)_2$

4. Water, H_2O

   $2(1.01) + 16$

   18.02 g/mol H_2O

Now that we have a balanced chemical equation and know the molar masses of the substances involved, we are ready to do stoichiometry problems based upon gram masses. Basically, if the data species is given in grams, we use the molecular weight of the data species to convert it into moles. Then we use the stoichiometric mole-to-mole conversion factor to deduce the number of moles of the "answer" species involved. Then, if the answer is required to be expressed in grams, we use the molecular weight of the "answer" species to get the desired answer expressed in grams. This process is represented by a single string of dimensional analysis factors.

Example Problem 2: Using data and results from the equation on the previous page, determine the mass (in g) of water, H_2O produced from the complete reaction of 400.0 g of nitric acid, HNO_3.

The "data" species in the problem is HNO_3 (since we are given how much of this species that we have – i.e. 400.0 g) and the "answer" species is H_2O (since we are attempting to determine how much H_2O is produced from the reaction). The balanced chemical equation from the previous page tells us that 2 moles of HNO_3 and H_2O are involved (namely, two moles of HNO_3 produces 2 moles of H_2O). The calculated molecular weights are 63.02 g/mol forHNO$_3$ and 18.02 g/mol for H_2O.

400.0 g of HNO_3	1 mol HNO_3	2 moles H_2O	18.02 g H_2O	= 114.4 g of H_2O
	63.02 g HNO_3	2 moles HNO_3	1 mole H_2O	

Practice Problem 2: Using the data from Review Problems 1 and 2 and referring to the example in Example Problem 2, carry out the calculations necessary to determine each of the following quantities based upon the chemical equation present in Review Problem 1.

1. Calculate the mass (in g) of $Ba(OH)_2$ required to produce 100.0 g of H_2O.

100g H_2O	1 mol H_2O	1 mol $Ba(OH)_2$	171.35g $Ba(OH)_2$	= 475.44g $Ba(OH)_2$
	18.02g H_2O	2 mol H_2O	1 mol $Ba(OH)_2$	

2. Calculate the mass (in g) of HNO_3 required to react completely with 50.0 g of $Ba(OH)_2$.

50.0g $Ba(OH)_2$	1 mol $Ba(OH)_2$	2 mol HNO_3	63.02g HNO_3	= 36.78g HNO_3
	171.35g $Ba(OH)_2$	1 mol $Ba(OH)_2$	1 mol HNO_3	

Stoichiometry Graphic Organizer

Start?

1 Mass of substance A (g)

(given)

$\frac{1 \text{ mol}}{\text{☆Molar Mass of A (g)☆}}$ – PT

Start?

2 Moles of Substance A (mol)

(given)

Coefficients of balanced chemical equation

$\frac{\# \text{ mol B}}{\# \text{ mol A}}$

End?

3 Moles of Substance B (mol)

(find)

$\frac{\text{☆Molar Mass of B (g)☆}}{1 \text{ mol}}$ PT

End?

4 Mass of Substance B (g)

(find)

Stoichiometry Examples

$CaC_2\ (s) + 2H_2O\ (l) \rightarrow C_2H_2\ (g) + Ca(OH)_2\ (s)$

If given 25 grams of CaC_2, how many grams of $Ca(OH)_2$ would be produced?

$$\frac{25\text{ g } CaC_2}{} \left| \frac{1\text{ mol } CaC_2}{64.10\text{ g } CaC_2} \right| \frac{1\text{ mol } Ca(OH)_2}{1\text{ mol } CaC_2} \left| \frac{74.1\text{ g } Ca(OH)_2}{1\text{ mol } Ca(OH)_2} \right. = 28.9\text{ g } Ca(OH)_2$$

If given 1.35 grams of H_2O, how many moles of C_2H_2 would be produced?

$$\frac{1.35\text{ g } H_2O}{} \left| \frac{1\text{ mol } H_2O}{18.02\text{ g } H_2O} \right| \frac{1\text{ mol } C_2H_2}{2\text{ mol } H_2O} = 0.0374\text{ mol } C_2H_2$$

$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$

If given 45.89 moles of H_2SO_4, how many moles of NH_3 would be required?

$$\frac{45.89\text{ mol } H_2SO_4}{} \left| \frac{2\text{ mol } NH_3}{1\text{ mol } H_2SO_4} \right. = 91.78\text{ mol } NH_3$$

If given 0.890 moles of NH_3, how many grams of $(NH_4)_2SO_4$ would be produced?

$$\frac{0.890\text{ mol } NH_3}{} \left| \frac{1\text{ mol } (NH_4)_2SO_4}{2\text{ mol } NH_3} \right| \frac{132.17\text{ g } (NH_4)_2SO_4}{1\text{ mol } (NH_4)_2SO_4} = 5$$

Limiting Reactants Notes

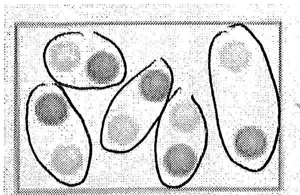
Limiting Reactant – A reactant that is consumed completely in a reaction (runs out 1st)

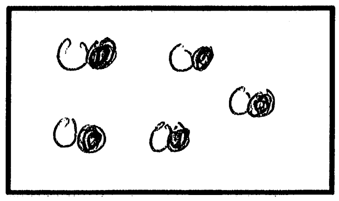
Excess Reactant – A reactant that will not be used up in a reaction (some left over)

Visual Representations:

Fe = Dark Circles, S = light circles

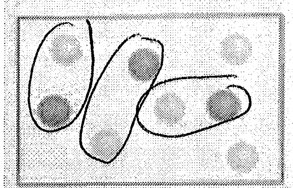
FeS is the product of this reaction. Draw the products in the box below.

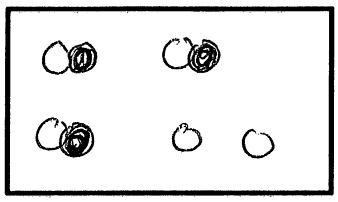




Which reactant is limiting? Both

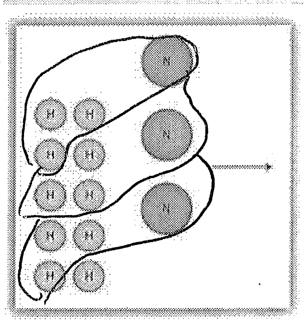
Which reactant is in excess? None



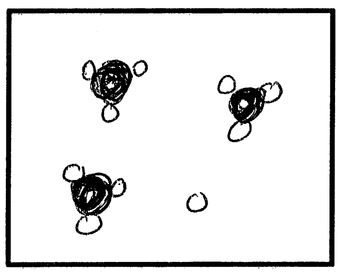


Which reactant is limiting? Fe

Which reactant is in excess? S



NH_3 is the product of this reaction. Draw the products in the box below.



Which reactant is limiting? N

Which reactant is in excess? H

In a problem, with a visual representation, when deciding which reactant is limiting and which is in excess, it is important that we are comparing like substances (apples to apples). Therefore we must convert one reactant into the units of another so that we are not trying to compare apples oranges.

Example #1

A? $2NaCl + Pb(NO_3)_2 \rightarrow 2NaNO_3 + PbCl_2$ B

Problem: In a reaction of 15.3 g of NaCl with 60.8 g of $Pb(NO_3)_2$ (A?) how many grams of $PbCl_2$ will be produced?

Solution: 1. **Change both given amounts to moles. Then, change the first chemical into the moles of the other, using the mole-to-mole ratio.**

$$\frac{15.3\,g\,NaCl}{} \left| \frac{1\,mol\,NaCl}{58.44\,g\,NaCl} \right| \frac{1\,mol\,Pb(NO_3)_2}{2\,mol\,NaCl} = 0.1309\,mol\,Pb(NO_3)_2$$

$$\frac{60.8\,g\,Pb(NO_3)_2}{} \left| \frac{1\,mol\,Pb(NO_3)_2}{331.22\,g\,Pb(NO_3)_2} \right. = 0.1835\,mol\,Pb(NO_3)_2$$

2. Whichever number above that is **smallest**, that chemical is the **limiting reactant**. The other chemical is then considered the excess reactant (a synonym for reactant is reagent – you will see both).

Limiting Reactant: NaCl   Excess Reactant: $Pb(NO_3)_2$

15.3g NaCl

3. Using the limiting reactant as your given amount, calculate answer for product (from the question).

$$\frac{15.3\text{ g NaCl}}{} \left| \frac{1\text{ mol NaCl}}{58.44\text{ g NaCl}} \right| \frac{1\text{ mol PbCl}_2}{2\text{ mol NaCl}} \left| \frac{278.1\text{ g PbCl}_2}{1\text{ mol PbCl}_2} \right. = 36.4\text{ g PbCl}$$

4. Sometimes you will be asked to calculate the amount of excess reactant left over. To do this you will start your conversion with the limiting reactant again and convert to the mass of the excess reactant. Then you will **subtract the mass you calculate from that given in the problem for the excess reactant.**

$$\frac{15.3\text{ g NaCl}}{} \left| \frac{1\text{ mol NaCl}}{58.44\text{ g NaCl}} \right| \frac{1\text{ mol Pb(NO}_3)_2}{2\text{ mol NaCl}} \left| \frac{331.22\text{ g}}{1\text{ mol Pb(NO}_3)_2} \right. = 43.4\text{ g Pb(NO}_3)_2$$

60.8 g (given) − 43.4 g (used) = 17.4 g (left over) used by reaction

Example #2

$$2HCl + MgSO_4 \rightarrow MgCl_2 + H_2SO_4$$

Problem: In a reaction of 25.34 g HCl with 10.23 g of $MgSO_4$, how many grams of $MgCl_2$ will be produced?

Solution: 1. Show your work below to determine the limiting reactant.

$$\frac{25.34\text{ g HCl}}{} \left| \frac{1\text{ mol HCl}}{36.46\text{ g HCl}} \right| \frac{1\text{ mol MgSO}_4}{2\text{ mol HCl}} = 0.3475\text{ mol MgSO}_4$$

$$\frac{10.23\text{ g MgSO}_4}{} \left| \frac{1\text{ mol MgSO}_4}{120.38\text{ g MgSO}_4} \right. = 0.084999\text{ mol MgSO}_4$$

2. Limiting Reactant: $MgSO_4$ Excess Reactant: HCl

3. Using the limiting reactant as your given amount, calculate answer for product.

$$\frac{10.23\text{ g MgSO}_4}{} \left| \frac{1\text{ mol MgSO}_4}{120.38\text{ g MgSO}_4} \right| \frac{1\text{ mol MgCl}_2}{1\text{ mol MgSO}_4} \left| \frac{95.21\text{ g MgCl}_2}{1\text{ mol MgCl}_2} \right. = 8.091\text{ g MgCl}_2$$

4. How much of the excess reactant will be left over?

$$\frac{10.23\text{ g MgSO}_4}{} \left| \frac{1\text{ mol MgSO}_4}{120.38\text{ g MgSO}_4} \right| \frac{2\text{ mol HCl}}{1\text{ mol MgSO}_4} \left| \frac{36.46\text{ g HCl}}{1\text{ mol HCl}} \right. = 6.197\text{ g HCl}$$

used by reaction

25.34 g (given) − 6.197 g (used) = 19.14 g left over

Heat in Stoichiometry Problems Notes

The amount of each transferred during a reaction is called the **molar enthalpy of reaction** (ΔH_{rxn}). It is reported in kilojoules per mole of reactant. A reaction that produces heat is exothermic and has a negative (-) ΔH_{rxn}. A reaction that absorbs heat is endothermic and has a positive (+) ΔH_{rxn}.

Consider the following example problem:

How much heat is produced when 85 g of sulfur reacts according to the following reaction?

2 S + 3 O2 → 2 SO3 ΔH = -792 kJ

Follow these steps to solve these kinds of problems.

A. Write down the given information
B. Convert given information into moles. (If you are given moles in the problem, you can skip this step)
C. Once in moles, use coefficient and ΔH to convert from moles to kJ.
D. Cancel units and solve, rounding to correct significant figures

Step: (A) (B) (C) (D)

$$\frac{85\text{ g S}}{} \left| \frac{1\text{ mol S}}{32.07\text{ g S}} \right| \frac{-792\text{ kJ}}{2\text{ mol S}} = -1049.58\text{ kJ} = \boxed{-1050\text{ kJ}}$$

(molar mass

Let's try another example problem:

How much heat will be released when 6.44 g of sulfur reacts with excess oxygen, according to the reaction above? (Use the steps above to guide your set-up.)

Step: (A) (B) (C) (D)

$$\frac{6.44\text{ g S}}{} \left| \frac{1\text{ mol S}}{32.07\text{ g S}} \right| \frac{-792\text{ kJ}}{2\text{ mol S}} = -79.52\text{ kJ} = \boxed{-79.5\text{ kJ}}$$