Chemistry 11

Unit 4: Chemical Reactions & Stoichiometry

Book 2 : Stoichiometry

Name: KEY

Block:

Part A Intro to Stoichiometry - *Calculating with Chemical Change*

The reaction between phosphoric acid, H_3PO_4, and potassium hydroxide, KOH, can produce three different products:

A 1 H_3PO_4 + 1 KOH → KH_2PO_4 + H_2O

B 1 H_3PO_4 + 2 KOH → K_2HPO_4 + 2 H_2O

C 1 H_3PO_4 + 3 KOH → K_3PO_4 + 3 H_2O.

*ratio of reactants, Determines the products formed.

Each of the products KH_2PO_4, K_2HPO_4 and K_3PO_4, has different properties and different uses.

For example, KH_2PO_4 is used in baking powder, K_2HPO_4 is used in some fertilizers and antifreezes, and K_3PO_4 is used in liquid soaps.

The products of this chemical reaction are based on the MOLAR RATIO of H_3PO_4 and KOH used.

Stoichiometry (*stoicheion* meaning "element" and *metron* meaning "measure"): The relationship between amounts of reactants used, and the products produced. Quantitatively relate amounts of reactants & products

With stoichiometry, we can predict the amount of a specific product created when a given amount of reactant is used.

Example: $2\,H_2(g)$ + _ $O_2(g)$ → $2\,H_2O(l)$ synthesis

How does one state the chemical reaction equation above? It turns out that there are actually two ways:

"Two moles (molecules) of hydrogen react with one mole (molecule) of oxygen to produce two moles (molecules) of water."

the coefficients represent the mole ratio (# of molecules)

In chemistry we will usually think in terms of MOLES rather than molecules.

b/c it's nearly impossible to measure/weigh individual molecules ... and it would be a HUGE #.

The mole ratios of coefficients in the balanced reaction equation gives us the mole conversion factors:

MOLE RATIOS

2 mol H_2 : 1 mol O_2

2 mol H_2 : 2 mol H_2O

1 mol O_2 : 2 mol H_2O

Conversion Factors

eg. $\frac{2 \text{ mol } H_2}{1 \text{ mol } O_2}$ or $\frac{1 \text{ mol } O_2}{2 \text{ mol } H_2}$

each one.

EXAMPLE: Consider the reaction equation 1 $N_2 + 3\,H_2 \longrightarrow 2\,NH_3$.

How many molecules of N_2 are required to react with 15 molecules of H_2?

*coefficients can also refer to the number of molecules ... ratio is the same moles or molec.

since, 1 molecule of N_2 reacts with 3 molecules of H_2

then, 1 molec N_2 : 3 molec. H_2 $\frac{1 \text{ molec } N_2}{3 \text{ molec } H_2}$ (can be flipped.)

$$\frac{15 \text{ } \cancel{\text{molec } H_2}}{} \times \frac{1 \text{ molec } N_2}{3 \text{ } \cancel{\text{molec } H_2}} = \underline{\quad 5 \quad} \text{ molecules of } N_2$$

IMPORTANT: Use completely–labelled units (eg. "molecule N_2" not just "molecule") so you know which coefficient goes on top and which goes on the bottom of the conversion factor.

Too easy to get mixed up!

We can use these **conversion factors** to move from moles of one species to moles of another.

(reactants)

Example Suppose that 1.50 moles of aluminum were produced during a reaction between zinc and aluminum chloride. How many moles of zinc reacted?

Balanced Chemical Rxn: $3Zn_{(s)} + 2AlCl_{3(aq)} \rightarrow 2Al_{(s)} + 3ZnCl_{2(aq)}$

(single replacement)

Known: ? 1.50 mol

mol ratio: 3Zn : 2Al ⇒ $\frac{3 \text{ mol Zn}}{2 \text{ mol Al}}$ or $\frac{2 \text{ mol Al}}{3 \text{ mol Zn}}$

conversion factors

* Start with given value

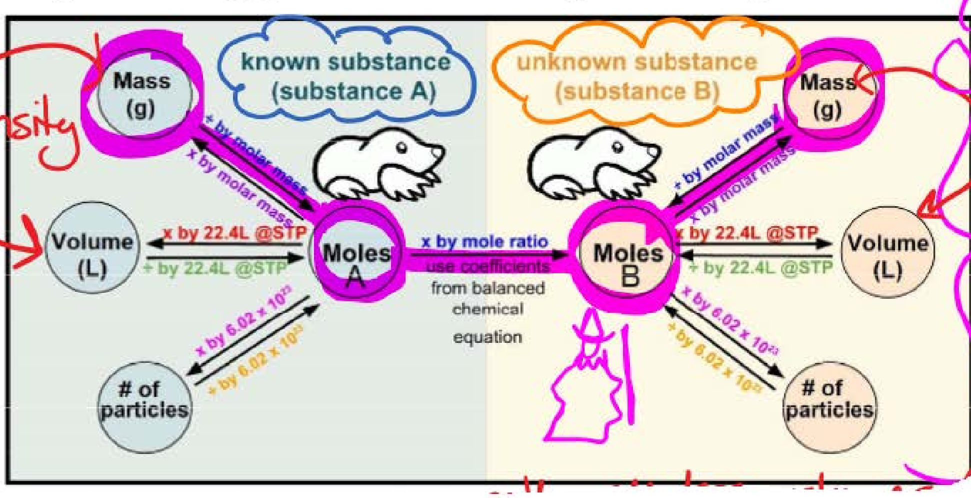
$$\frac{1.50 \cancel{\text{ mol Al}}}{} \times \frac{3 \text{ mol Zn}}{2 \cancel{\text{ mol Al}}} = \underline{2.25} \text{ mol Zn}$$

The Mole Bridge

As we have seen earlier, you can convert between the different species in the chemical reaction equation.
To do this, however, you must get your substances into MOLES!: **Only moles can cross the mole bridge!**

Using the mole bridge, you can ***convert*** between any of the following:

- a reactant and a product
- a reactant and a reactant
- a product and a product



all conversion factors from The Mole unit!

mostly cellulose, polymer of glucose ($C_6H_{12}O_6$)

Example 1 If 428.5 g of wood were combusted, then what mass of water would be expected to form?

① Balanced Rxn. $\underline{1}\,C_6H_{12}O_6 + \underline{6}\,O_2 \rightarrow \underline{6}\,CO_2 + \underline{6}\,H_2O$ 18.0

② Know: 428.5 g $C_6H_{12}O_6$? g H_2O

③ Plan mass Ⓐ → moles Ⓐ → mole Ⓑ → mass Ⓑ

④ Calc:

$$\frac{428.5 \cancel{g\, C_6H_{12}O_6}}{} \times \underbrace{\frac{1 \cancel{\text{ mol } C_6H_{12}O_6}}{180.0 \cancel{g\, C_6H_{12}O_6}}}_{\text{molar mass}} \times \underbrace{\frac{6 \cancel{\text{ mol } H_2O}}{1 \cancel{\text{ mol } C_6H_{12}O_6}}}_{\text{mole ratio}} \times \underbrace{\frac{18.0 g\, H_2O}{1 \cancel{\text{ mol } H_2O}}}_{\text{molar mass}} = \boxed{257.1 g\, H_2O}$$

$C_5H_{12}O_{(l)}$ react with $O_{2(g)} \rightarrow CO_{2(g)} + H_2O_{(g)}$

Example 2 If 100.0 mL of 1-pentanol were combusted then what volume of CO_2 would form, given that the volume would be determined under conditions of STP? (note: $d_{\text{1-pentanol}} = 0.881$ g/mL)

22.4L = 1 mol

Balanced Rxn: $\underline{2}\ C_5H_{12}O_{(l)} + \underline{15}\ O_2 \rightarrow \underline{10}\ CO_{2(g)} + \underline{12}\ H_2O_{(g)}$

Known: 100.0 mL (A) ... ? vol (B)

plan: volume (A) $\xrightarrow{\text{density}}$ mass (A) $\xrightarrow{\text{molar mass}}$ mol (A) $\xrightarrow{\text{mole ratio}}$ mol (B) $\xrightarrow{\text{molar volume}}$ vol (B)

Any gas @ STP

100.0 mL $\cancel{C_5H_{12}O}$	0.881 g $\cancel{C_5H_{12}O}$	1 mol $\cancel{C_5H_{12}O}$	10 mol CO_2	22.4 L CO_2
	1 mL $\cancel{C_5H_{12}O}$	88.0 g $\cancel{C_5H_{12}O}$	2 mol $\cancel{C_5H_{12}O}$	1 mol CO_2
	density as conversion factor	molar mass 1-pentanol	mole ratio (coefficients)	molar volume

3 s.f.

= $\boxed{112\ L\ CO_2}$ (volume $CO_{2(g)}$)

(112.127...)

PRACTICE What mass of C_3H_8 is required to produce 100.0g of H_2O?

$\underline{1}\ C_3H_{8(l)} + \underline{5}\ O_{2(g)} \rightarrow \underline{3}\ CO_{2(g)} + \underline{4}\ H_2O_{(l)}$

? g C_3H_8 ... 100.0g H_2O

mass H_2O → moles H_2O → moles C_3H_8 → mass C_3H_8

100.0g H_2O	1 mol H_2O	1 mol C_3H_8	44.0g C_3H_8
	18.0g H_2O	4 mol H_2O	1 mol C_3H_8
	molar mass	mol ratio	molar mass

= 61.1 g C_3H_8

(3 s.f.)

chemistry homework

Assignment #1: "Basic Stoichiometry Problems" & "Mole Ratio in Reactions" *Complete ALL assignments on a separate piece of paper and attach to your booklet.*

Basic Stoichiometry Problems

Answers
1. 6.8 g NH_3
2. 22 g Fe
3. 3.09×10^3 g CO_2
4. 2.17 g Al
5. 4.91 g Zn
6. 0.30 L HNO_3 (300 mL)
7. 7.5 M HCl
8. 0.0094 L $AgNO_3$ (9.4 mL)
9. 0.341 M KOH
10. 0.45 L (450 mL)
11. 0.78 g $Al(OH)_3$
12. 3.50 M HCl
13. 1.91 g Cu
14. 120 kg O_2

1. What mass of ammonia forms when 5.6 g of nitrogen reacts?
   $N_2 + 3H_2 \rightarrow 2NH_3$

2. What mass of iron must be reacted to produce 32 grams of iron (III) oxide?
   $4Fe + 3O_2 \rightarrow 2Fe_2O_3$

3. What mass of carbon dioxide forms when 1.00 kg of octane is burned?
   $2C_8H_{18} + 25O_2 \rightarrow 16CO_2 + 18H_2O$

4. What mass of aluminum is needed to react with 6.4 g of iron (III) oxide?
   $2Al + Fe_2O_3 \rightarrow Al_2O_3 + 2Fe$

5. What mass of zinc will react with 50.0 mL of 3.00 M HCl?
   $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

6. How many mL of 2.00 M HNO_3 is needed to consume 5.4 g of aluminum?
   $2Al + 6HNO_3 \rightarrow 2Al(NO_3)_3 + 3H_2$

7. 2$\underline{0}$ mL of HCl is needed to consume 2.8g Fe. What is the concentration of HCl?
   $2Fe + 6HCl \rightarrow 2FeCl_3 + 3H_2$

8. How many mL of 0.80 M $AgNO_3$ will exactly react with 10.0 mL of 0.25 M $AlCl_3$?
   $3AgNO_3 + AlCl_3 \rightarrow 3AgCl + Al(NO_3)_3$

9. 25.0 mL of 0.240M H_2SO_4 react exactly withy 35.2 mL of KOH. Determine the concentration of KOH. $H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$

10. How many mL of 0.60M H_3PO_4 will react with 3$\underline{0}$ g of $Ca(OH)_2$?
    $2H_3PO_4 + 3Ca(OH)_2 \rightarrow Ca_3(PO_4)_2 + 6H_2O$

11. What mass of aluminum hydroxide would react exactly with 15.0 mL of 2.00M HCl?
    $3HCl + Al(OH)_3 \rightarrow AlCl_3 + 3H_2O$

12. What concentration HCl is needed so that 40$\underline{0}$ mL will react with 17.0 g of magnesium? $Mg + 2HCl \rightarrow MgCl_2 + H_2$

13. What mass of copper will react with 10.0 mL of 12.0 M nitric acid?
    $Cu + 4HNO_3 \rightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$

14. How many kilograms for oxygen are needed to react with 51 kg of ammonia?
    $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

Chap 7: Mole Ratio in Reactions

1. How many moles of O_2 are produced from 1.50 moles of $KClO_3$?
   $2KClO_3 \rightarrow 2KCl + 3O_2$

2. How many moles of H_2 are needed to react with 8.0 moles of N_2?
   $N_2 + 3H_2 \rightarrow 2NH_3$

3. How many moles of HCl are needed to form 4.5 moles of H_2?
   $2Al + 6\,HCl \rightarrow 2AlCl_3 + 3H_2$

4. How many moles of water form when 0.50 moles of O_2 react?
   $4NH_3 + 7O_2 \rightarrow 4NO_2 + 6H_2O$

5. How many moles of methane can react with 24.0 moles of O_2?
   $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

6. How many moles of calcium phosphate form when 2.0 moles of $Ca(OH)_2$ react?
   $3Ca(OH)_2 + 2H_3PO_4 \rightarrow Ca_3(PO_4)_2 + 6H_2O$

7. How many moles of Mg can react with 0.40 mol HCl?
   $Mg + 2HCl \rightarrow MgCl_2 + H_2$

8. How many moles of $NaHCO_3$ must decompose to produce 0.80 mol H_2O?
   $2NaHCO_3 \rightarrow Na_2O + 2CO_2 + H_2O$

Answers:

1. 2.25 mol
2. 24 mol
3. 9.0 mol
4. 0.43 mol
5. 12.0 mol
6. 0.67 mol
7. 0.20 mol
8. 1.6 mol

Part B: Stoichiometry Calculations Involving - Molar Concentration

Remember... concentration $\frac{mol}{L} = M$ → $M = C = \frac{n}{V}$ ← number of moles; ← volume in LITRES (L)

Stoichiometry calculations are based on the relationship of moles of 1 chemical and moles (or molecules) of another chemical. ← based on a MOLE RATIO! (always try to convert to mol)

$C = \frac{n}{V}$ ∴ $n = C \cdot V$ ∴ $V = \frac{n}{C}$

2 Types of problems involving volume:

1) Use "22.4L" (1 mol = 22.4L) a gas @ STP

2) Calculate... volume or Molarity when it's NOT a gas or NOT @ STP (often find concentration $\frac{mol}{L}$ used as a conversion factor.)

IMPORTANT: If a VOLUME is mentioned, and the problem involves a molarity, DO NOT assume that "22.4 L" should be used. The use of "22.4 L" is justified only if the substance being referred to is a **gas** AND if the key phrase "**at STP**" is mentioned along with the volume.

Example 1

Tums™ is an antacid composed primarily of calcium carbonate (chalk) $CaCO_{3(s)}$, and stomach acid is a dilute solution of hydrochloric acid. The neutralization reaction between $CaCO_3$ and stomach acid is represented by the equation:

Balanced Rxn: $1\,CaCO_3(s)$ (A) + $2\,HCl(aq)$ (B, ? L) ----> $CaCl_2(aq) + CO_2(g) + H_2O(l)$ ← $H_2O_{(l)}$

Know: 0.750g 0.001M

a) A tablet of Tums™ has a mass of 0.750 g. What volume of stomach acid having [HCl] = 0.0010 M is neutralized by a 0.750 g portion of CaCO3?

plan: mass (A) $\xrightarrow{\text{molar mass } CaCO_3 = 100.1g}$ mol (A) $\xrightarrow{\text{mole ratio}}$ mol (B) → volume (B)

Molarity = $\frac{mol}{L}$ = 0.001 M = $\boxed{\frac{0.001\,mol}{1\,L}}$

$$\frac{0.750\,g\,CaCO_3}{} \times \frac{1\,mol\,CaCO_3}{100.1\,g\,CaCO_3} \times \frac{2\,mol\,HCl}{1\,mol\,CaCO_3} \times \frac{1\,L\,HCl}{0.0010\,mol\,HCl} = \underline{15}\,L\,HCl$$

14.99.....

3s.f. 2s.f

b) What volume of $CO_{2(g)}$ at STP is produced if 1.25 L of 0.0055 M HCl reacts with an excess of $CaCO_3$? 1 mol = 22.4L

$CaCO_3 + 2HCl$ (A) $\rightarrow CaCl_2 + 1CO_{2(g)}$ (B) $+ H_2O$

Known: $M = \frac{mol}{L} = \boxed{\frac{0.0055\,mol}{1\,L}}$; 1.25L; 1 mol = 22.4L, ? L (vol.) molar volume

plan: volume HCl $\xrightarrow{\text{molarity}}$ mol HCl $\xrightarrow{\text{mole ratio}}$ mol CO_2 $\xrightarrow{\text{molar volume}}$ volume CO_2

$$\frac{1.25\,\cancel{L\,HCl}}{} \times \underbrace{\frac{0.0055\,mol\,HCl}{1\,\cancel{L\,HCl}}}_{\text{molarity}} \times \frac{1\,mol\,CO_2}{2\,mol\,HCl} \times \frac{22.4\,L\,CO_2}{1\,mol\,CO_2} = \underline{0.077}\,L\ of\ CO_2$$

2s.f. 2s.f.

Example 2 Consider the following reaction:

$1\ H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$

$0.100M = \frac{0.100\ mol}{1\ L}$

a) What mass (in g) of water is produced when 125mL of a 0.100M H_2SO_4 solution is reacted ~~with excess KOH?~~

0.125L

volume H_2SO_4 → mol H_2SO_4 → mol H_2O → mass H_2O

0.125L H_2SO_4	0.100 mol H_2SO_4	2 mol H_2O	18.0g H_2O
3sf	1L H_2SO_4	1 mol H_2SO_4	1 mol H_2O
	molarity as conversion.	mole ratio	molar mass

$\boxed{= 0.450\ g\ H_2O}$

3sf.

b) What volume of 0.050M KOH solution is needed to completely react with 78mL of 0.28M H_2SO_4?

÷1000

$\frac{0.050\ mol}{1\ L}$ can flip!

0.078L ↳ $\frac{0.28\ mol}{1\ L}$

volume H_2SO_4 $\xrightarrow{molarity}$ mol H_2SO_4 → mol KOH $\xrightarrow{molarity.}$ vol KOH

0.078L H_2SO_4	0.28mol H_2SO_4	2 mol KOH	1 L KOH
2sf.	1 L H_2SO_4	1 mol H_2SO_4	0.050mol KOH

0.8736...

$\boxed{0.87\ L\ KOH}$

Part C: Titration Reactions

A **TITRATION** is a method used to determine the concentration of an unknown solution.

- **How You Do It:**

  Measure the volume of the solution of known concentration (the ***known solution***) needed to completely react with a certain volume of the solution of unknown concentration (the ***unknown***).

- **Why It Works:**

HCl (Analyte): mol HCl = (concentration)(volume)

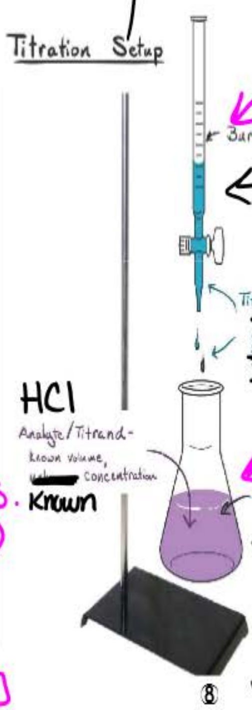
color change = "equivalence point" = equal mols. (mole ratio)

mol HCl = mol NaOH (1:1 ratio)

[NaOH] = Molarity = $\frac{\text{mol NaOH}}{\text{volume (L)}}$ = $\frac{?}{}$ [NaOH] "unknown"

How much you added from burette

Titration Setup



"Titrant"

← [?]

NaOH unknown ∴ known volume

HCl known

"Analyte"

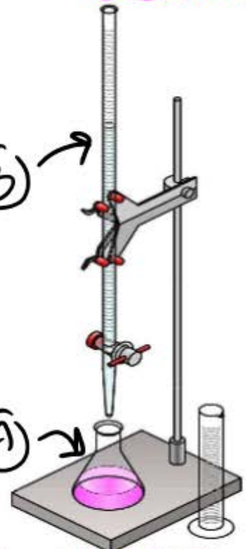
Add an indicator to show the color change mol(A) = mol(B) burette (titrant)

A **Titration** is a process in which a **measured** amount of a solution is reacted with known volume of another solution *(one of the solutions has an* **unknown** *concentration)* until a desired **EQUIVALENCE POINT** is reached.

Analyte (flask)

EQUIVALENCE POINT (Stoichiometric Point): the point in the titration when all reactants have been used up. The mol of acid (H^+) are equal to the moles of base (OH^-) (mol ratio from equation)

The equivalence point is recognized by an indicator ⇒ change colour ~pH 7



There are many different types of titrations but they all work on the same principle:

*(In Chemistry 11, we will only look at **Acid-Base Reaction Titrations**.)*

eg. $A + B \longrightarrow C + D$

- As you combine the solutions, the chemicals react, consuming each other to form products.
  1. Until you've added enough of reactant B reactant A is in excess ↑
  2. Once you've added just enough to complete the reaction, A=B (equivalence point)
  3. Adding more of reactant B (after reaction is over) results in reactant B "in excess" ↑
- The **equivalence point** is the "point" in the acid-base titration where all the reactants have been used up (and none are in excess); the number of moles of each reactant perfectly obeys the stoichiometry (mole ratios) of the reaction equation. ⇒ balanced equation

Example 3

$0.0500L$ [HCl] = ?

When ~~50.0 mL~~ of HCl were titrated with 0.250 M NaOH, it was determined that 75.0 mL (0.075L) were needed to reach the **equivalence** point. Determine the [HCl]. ← M

mole ratio = $H^+ : OH^-$ 1:1

$1\,HCl_{(aq)} + 1\,NaOH_{(aq)} \longrightarrow 1\,NaCl_{(aq)} + 1\,H_2O_{(l)}$

① mol of base (NaOH)

mols NaOH = (0.250M)(0.075L)

mols NaOH = 0.01875 mol

$M = \frac{mol}{L}$

∴ mol = (M)(vol.)

② @ equivalence point
mol NaOH = mol HCl (1:1)

③ mol of acid (HCl) = 0.01875 mol HCl

Molarity: $[HCl] = \frac{mol}{vol.(L)} = \frac{0.01875\,mol}{0.0500\,L}$

$\boxed{[HCl] = 0.375\,M}$

Example 4 If 19.8 mL (0.0198L) of phosphoric acid reacts completely with 25.0 mL (0.0250L) of 0.500 M KOH, then what is the concentration of the phosphoric acid?

$1\,H_3PO_{4(aq)} + 3\,KOH_{(aq)} \longrightarrow 1\,K_3PO_{4(aq)} + 3\,H_2O_{(l)}$

$H^+ : OH^-$ 1:3 } @ equivalence point.

Two methods:

(A) ① mol KOH = (0.500M)(0.0250L)
= 0.0125 mol KOH

② @ equivalence point mol KOH : mol H_3PO_4
3 : 1

$0.0125\,mol\,KOH \times \frac{1\,mol\,H_3PO_4}{3\,mol\,KOH} = 0.0041666\,mol\,H_3PO_4$

③ $[H_3PO_4] = \frac{mol}{vol(L)} = \frac{0.004166\,mol}{0.0198\,L} = \boxed{0.210\,M\,H_3PO_4}$

(B) vol. KOH $\xrightarrow{molarity}$ mol KOH $\xrightarrow{mole\ ratio}$ mol H_3PO_4 → [H_3PO_4]

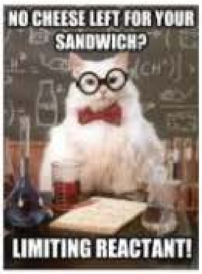
$$0.0250\,L\,KOH \times \underbrace{\frac{0.500\,mol\,KOH}{1\,L\,KOH}}_{molarity} \times \underbrace{\frac{1\,mol\,H_3PO_4}{3\,mol\,KOH}}_{mole\ ratio} \times \frac{1}{0.0198\,L\,H_3PO_4} = \boxed{0.210\,M\,H_3PO_4}$$

Prepare Acid Base Titration Lab:
- flow chart
- pre-lab questions
- set up data tables

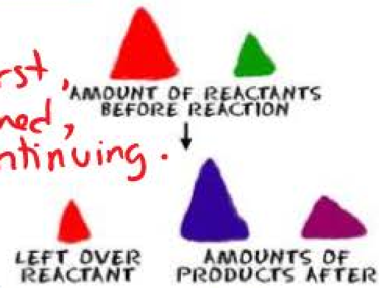
chemistry homework

Assignment #2: Hebden Questions #17-23 pg 131
*Complete ALL assignments on a separate piece of paper and attach to your booklet when handing in at the end of the unit. Be sure to **clearly number each assignment with a heading.***

Part D: Stoichiometry of Limiting & Excess Quantities



Limiting Reactant: (L.R.)
the reactant that runs out first, which "Limits" the product formed, or stops the reaction from continuing.
*the L.R. controls how much product is formed.



Excess Reactant:
the reactant which does not run out, there will be some of this left over, "in excess" when the reaction is complete.

Since the ***limiting reactant*** is what determines when the reaction is over, it is this quantity that we use for stoichiometric calculation. } use to find out how much product?

ANIMATION: https://phet.colorado.edu/en/simulation/reactants-products-and-leftovers

Let's consider an analogy: Suppose I'm making a sandwich. In each sandwich I want:

2 pieces of bread (Br)
4 slices of tomato (To)
2 pieces of chicken (Ch)

reactants / product

$\boxed{2Br + 4To + 2Ch} \rightarrow \boxed{1Br_2To_4Ch_2}$

How much product can be made from each reactant

BUT...what if I had 10 slices of bread, 26 tomatoes and 12 chicken slices?

start with "known" amounts of each reactant.

10Br	1 sandwich
	2 Br

= 5 sandwiches

26To	1 sandwich
	4 To

= 6.5 sandwiches

12 Ch	1 sandwich
	2 Ch

= 6 sandwiches

L.R. is always the smallest amount of moles

excess reactants (ex. "more than enough")

Br is the limiting reactant (reagent), because we can only make 5 sandwiches, then we are all out of bread, and have an excess of Tomato + Chicken

...Similarly, chemical reactions frequently are carried out in such a way that one or more of the reactants actually are present in excess amounts. (only ever 1 Limiting reactant)

Some reasons for having an excess amount:

- deliberately adding an excess of 1 reactant to make sure all of a second reactant used (maybe too expensive to waste, or harmful to the environment)
- unavoidably having a reactant in excess because a limited amount of another reactant is available.

The reactant that gets used up first is called the ***limiting reactant*** because it limits how far the reaction can go. All other reactants that are left over after the reaction is finished are called ***excess reactants***.

determines the amount product formed

Consider the simple reaction: $2\,Na(s) + 1\,Cl_2(g) \rightarrow 2\,NaCl(s)$.

- How many moles of Cl_2 would you need to use up 2 moles of sodium? *Answer: 1 mole.*
- What would happen if 3.0 moles of sodium and 2.0 moles of chlorine reacted?

  Answer: Since 3.0 moles of sodium is only sufficient to react with 1.5 moles of chlorine, all of the sodium will be consumed and 0.50 moles of chlorine will be left in excess. (2:1 ratio)

- If 50.0 g Na and 80.5 g Cl_2 were reacted?

  Answer: You cannot directly compare numbers of atoms by comparing masses. You must convert to moles to compare: moles Na = 50.0 g / 23.0 g/mol = 2.17 mol; moles Cl_2 = 80.5 g/ 71.0 g/mol = 1.13 mol — 2:1 mole ratio

  You don't have enough Na to use up the Cl_2 (need 2.26 mol Na to use up 1.13 mol Cl_2)

  So Na *is the limiting reactant,* 1.085 *mole of* Cl_2 *reacts, and* 0.045 *mole of* Cl_2 *remains.* (excess)

To use up all 2.17 moles of Na you would need 1.085 *moles of* Cl_2

How to Determine the Limiting Reactant, Amount of Product(s) and Quantity of Excess Reactant(s):

1. Start by assuming that the first reactant is the limiting reactant (*i.e.* it gets used up before the others). Calculate how much product it could theoretically produce.
2. Repeat step 1, in turn, for each of the other reactants.
3. Identify the **Limiting Reactant** (***LR***) – the one that can make the least amount of product.

   Amount of Product Formed = amount of product formed based on amount of LR that reacted
4. Identify the **Excess Reactants** (***XSR***) that remain unreacted.
5. Use the *LR* to find out how much of the other *XSR(s)* remain. ***Amount of XSR remaining*** $= XSR_{initial} - XSR_{reacted}$

Consider the reaction between carbon monoxide and oxygen gas:

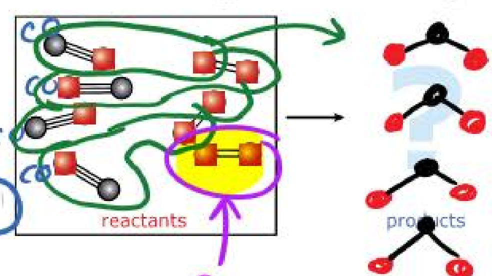
ideal reaction

$2\,CO_{(g)}$ +	$O_{2(g)}$ →	$2\,CO_{2(g)}$
2 molecules	1 molecule	2 molecules
2 mol	1 mol	2 mol
2L	1L	2L
2(28.0g)=56.0g	32.0 g	2(44.0g)=88.0g

Stoichiometric quantities would be present IF the amounts or volumes of CO O_2 reduced to 2:1

reality: 4 : 3 : 4

$2\,CO(g) + O_2(g) \longrightarrow 2\,CO_2(g)$



O_2 (left over)

However, this is rarely the case in the "real world". It is more likely that the number of particles will **NOT be in stoichiometric quantities**, or "perfect" ratios.

One or more reactant(s) is likely to be in excess.

Meaning, there will be more that enough of one reactant to completely react with the other.

a) Which of the reactant is in excess? O_2

b) Sketch any remaining reactants and products to show what will be present once the reaction is complete.

c) How many CO2 particles are formed? 4 moles of CO_2

d) How many excess reactant particles remain?

1 molecule of O_2

∴ CO was the limiting reactant

Types of Problems.

(A) • In **limiting and excess problems**, you will be given the mass of all of the reactant species and you must determine which of these are in excess...and more importantly, *which is the limiting reactant* (or reagent) that limits the amount of the product that can form.

(B) • You may also have to determine **how much of the excess species remains** once the reaction is complete.

as a mass.

Example 1 What volume of hydrogen gas ($H_{2(g)}$), measured at STP, is produced when 8.0g of lithium metal ($Li_{(s)}$) is reacted with 10.0g of water ($H_2O_{(l)}$)? What mass of the excess reactant remains once the reaction is completed?

(A)

(1) balanced equation (single replacement)

$$\underline{2}\,Li_{(s)} + \underline{2}\,H_2O_{(l)} \longrightarrow \underline{1}\,H_{2(g)} + \underline{2}\,LiOH_{(aq)}$$

OH^- H^+

(2) determine which reactant is in excess: compare moles

start with known/given amounts (mass)

$$\frac{8.0g\,Li \mid 1\,mol\,Li}{\mid 6.9g\,Li} = 1.20\,mol\,Li \text{ (excess reactant)}$$

which reagent is in excess?

which reagent is limiting?

$$\frac{10.0g\,H_2O \mid 1\,mol}{\mid 18.0g\,H_2O} = 0.556\,mol\,H_2O \text{ (Limiting reactant)}$$

Li : H_2O
2 : 2
1 : 1
1.2 : 0.556

The equation shows that 1 mol Li would require 1 mol H_2O to completely react. That means there is **insufficient** H_2O to use up all the Li

(3) What Volume of $H_{2(g)}$ is produced by Li? by H_2?

Now we must consider the "Theoretical Yield"... meaning how much product would be made from each of these amounts.

$$\frac{1.20\,mol\,Li \mid 1\,mol\,H_2 \mid 22.4L\,H_2}{\mid 2\,mol\,Li \mid 1\,mol\,H_2} = \underline{13.44}\,L\,H_{2(g)}$$

The reactant that produces the lowest yield (amount of product) is Limiting reactant

*The reactant that forms the **greater quantity of product** is in* excess

$$\frac{0.556\,mol\,H_2O \mid 1\,mol\,H_2 \mid 22.4L\,H_2}{\mid 2\,mol\,H_2O \mid 1\,mol\,H_2} = \underbrace{\underline{6.22}\,L\,H_{2(g)}}_{\text{"Lowest yield"}}$$

* Therefore the actual amount of product formed in this reaction will be 6.22 L $H_{2(g)}$

The actual amount of product formed is determined by the limiting reactant.

what is the lowest amount of product formed? what is the limiting reactant

(B) To determine *"mass of the excess reactant that remains once the reaction is completed"*

⇒ "how much Li is left over once all the H_2O is used up?"

... we must solve for How much Li is used by by the limiting reactant (10.0g H_2O)

(1) • begin with the **limiting reagent**

• use stoichiometry to determine how much of the **excess reactant** this will "use up"

• Subtract the amount used from the amount of "excess reagent" present at the start

• check significant figures (*sig figs*)

$$\frac{10.0g\,H_2O \mid 1\,mol\,H_2O \mid 2\,mol\,Li \mid}{\mid 18.0g\,H_2O \mid \underbrace{2\,mol\,H_2O}_{\text{mole ratio}} \mid} = \_\_\,g\,Li$$

mass limiting

mass excess

2 Parts to Limiting/Excess Problems

- A. In **limiting and excess problems**, you will be given the mass of all of the reactant species and you must determine which of these are in excess...and more importantly, *which is the limiting reactant* (or reagent) that limits the amount of the product that can form.
- B. You may also have to determine **how much of the excess species remains** once the reaction is complete.

check Hydrogen Rule. (activity series)

Example 1 What volume of hydrogen gas (product $H_{2(g)}$), measured at STP, is produced when 8.0g of lithium metal ($Li_{(s)}$) is reacted with 10.0g of water ($H_2O_{(l)}$)? What mass of the excess reactant remains once the reaction is completed?

balanced equation
(single replacement)

A. $\underline{2}\,Li_{(s)} + \underline{2}\,H_2O_{(l)} \rightarrow \underline{1}\,H_{2(g)} + \underline{2}\,LiOH_{(aq)}$

determine which reactant is in excess...compare moles.

which reagent is in excess?
which reagent is limiting?

The equation shows that ____ mol Li would require ____ mol H_2O to completely react. That means there is **insufficient** ____ to use up all the ____

start with known amounts of reactants:

$$\frac{8.0\text{g Li}}{} \times \frac{1\text{ mol Li}}{6.9\text{g Li}} \times \frac{1\text{ mol } H_2}{2\text{ mol Li}} = \underline{0.58}\text{ mol } H_2 \quad \Big\}\text{ excess reactant}$$

$$\frac{10.0\text{g } H_2O}{} \times \frac{1\text{ mol } H_2O}{18.0\text{g } H_2O} \times \frac{1\text{ mol } H_2}{2\text{ mol } H_2O} = \boxed{\underline{0.28}\text{ mol } H_2} \quad \Big\}\text{ Limiting Reactant}$$

What Volume of $H_{2(g)}$ is produced by Li?

by H_2?

Convert mass of reactants $\longrightarrow$ moles of product

The reactant that produces the lowest yield (amount of product) is ____

The reactant that forms the ***greater quantity of product*** *is in* ____

Therefore the actual amount of product formed in this reaction will be ____

What volume of $H_{2(g)}$ will be produced?
(amount of product formed)
mol product $\longrightarrow$ volume product.

(0.277....)

$$\frac{0.28\,\cancel{\text{mol } H_2}}{} \times \frac{22.4\text{ L } H_2}{1\,\cancel{\text{mol } H_2}} = \boxed{6.22\text{ L } H_{2(g)}}$$

To determine *"mass of the excess reactant that remains once the reaction is completed"*

- begin with the **limiting reagent**
- use stoichiometry to determine how much of the **excess reactant** this will "use up"
- Subtract the amount used from the amount of "excess reagent" present at the start
- check significant figures *(sig figs)*

B. How much of the excess reactant is left over? $\leftarrow$ need to know how much is used up in the rxn with H_2O?

8.0g Li + 10.0g H_2O

mass $H_2O \rightarrow$ mol $H_2O \rightarrow$ mol Li $\rightarrow$ mass Li

$$\frac{10.0\text{g } H_2O}{} \times \frac{1\text{ mol } H_2O}{18.0\text{g } H_2O} \times \frac{2\text{ mol Li}}{2\text{ mol } H_2O} \times \frac{6.9\text{g Li}}{1\text{ mol Li}} = \underline{3.83\text{g Li}}$$

(How is used by 10.0g of H_2O)

How much in excess?

8.0g − 3.83g = 4.2g Li in excess
(started with) (used in reaction) (left over)

Example 2 20.0 g of hydrogen react with 100.0 g of oxygen.
Identify the limiting reactant and determine the mass of water formed and the mass of the excess reactant.

Balanced Equation: $\underline{2}\ H_{2(g)} + \underline{1}\ O_{2(g)} \longrightarrow \underline{2}\ H_2O_{(l)}$

All one step when I know I need to solve for "mass of product"

start by calculating the mass of product, H_2O, that would be formed by these amounts of each reactant

(A)

mass of H_2O (based on H_2) = $\dfrac{20.0\,g\ H_2}{} \times \dfrac{1\ mol\ H_2}{2.0\,g\ H_2} \times \dfrac{2\ mol\ H_2O}{2\ mol\ H_2} \times \dfrac{18.0\,g\ H_2O}{1\ mol\ H_2O} = \underline{180.0}\ g\ H_2O$ (excess)

mass of H_2O (based on O_2) = $\dfrac{100.0\,g\ O_2}{} \times \underbrace{\dfrac{1\ mol\ H_2}{32.0\,g\ O_2}}_{\text{molar mass}} \times \underbrace{\dfrac{2\ mol\ H_2O}{1\ mol\ O_2}}_{\text{mole ratio}} \times \dfrac{18\,g\ H_2O}{1\ mol\ H_2O} = \boxed{\underline{112.5}\ g\ H_2O}$

Limiting Reactant (least amount of product formed)

* There is enough Hydrogen to make 180.0 g of H_2O, but only enough Oxygen to make 112.5 g H_2O

So we say that "sets a limit" on the amount of H_2O formed. Therefore O_2 is the LIMITING REAGENT

(B)

H_2 is the excess reagent, and by how many grams?

We find the mass of H_2 in excess by finding the mass of H_2 which actually reacts based on either:

-mass of the limiting reactant

-or the mass of a product formed by the limiting reactant

Then, subtract the mass of H_2 which reacts from it's starting mass.

if 100.0g of O_2 reacts with 20.0g of H_2, how much H_2 is used up?

$$\dfrac{100.0\,g\ O_2}{} \times \dfrac{1\ mol\ O_2}{32.0\,g\ O_2} \times \underbrace{\dfrac{2\ mol\ H_2}{1\ mol\ O_2}}_{\text{mole ratio}} \times \dfrac{2.0\,g\ H_2}{1\ mol\ H_2} = \underline{12.5}\ g\ H_2$$

* means that 100.0g O_2 will react with (use up) 12.5g of H_2 .... so there is excess H_2 (leftover)

$$\underset{\text{(starting amount)}}{20.0\,g} - \underset{\text{(used in reaction)}}{12.5\,g} = \underset{\text{(in excess)}}{\boxed{7.5\ g\ H_{2(g)}}}$$

13

all of them

pick a simple ratio

PRACTICE Determine the mass of the excess reactants when 56.8 g of ferrous chloride ($FeCl_2$) react with 14.0 g of potassium nitrate and 40.0 g of muriatic acid (HCl) react as follows:

$$3\,FeCl_2 + KNO_3 + 4\,HCl \longrightarrow 3\,FeCl_3 + NO + 2\,H_2O + KCl$$

* in reactions with multiple products, pick ONE, and stick to it!

what is the LR? (what forms the least amount of product)

mol NO (based on $FeCl_2$): $\frac{56.8\,g\,FeCl_2}{} \Big| \frac{1\,mol\,FeCl_2}{126.8\,g\,FeCl_2} \Big| \frac{1\,mol\,NO}{3\,mol\,FeCl_2} = 0.149$ mol NO

mol NO (based on KNO_3): $\frac{14.0\,g\,KNO_3}{} \Big| \frac{1\,mol\,KNO_3}{101.1\,g\,KNO_3} \Big| \frac{1\,mol\,NO}{1\,mol\,KNO_3} = 0.138$ mol NO

Limiting Reactant

least amount of product formed

mol NO (based on HCl): $\frac{40.0\,g\,HCl}{} \Big| \frac{1\,mol\,HCl}{36.5\,g\,HCl} \Big| \frac{1\,mol\,NO}{4\,HCl} = 0.274$ mol NO

∴ $FeCl_2$ and HCl are in excess... but by how much?
How much of each is used up in the reaction with KNO_3 (Limiting reactant)?

mass of $FeCl_2$ in excess: start $\boxed{56.8\,g} - \left[\frac{14.0\,g\,KNO_3}{} \Big| \frac{1\,mol\,KNO_3}{101.1\,g\,KNO_3} \Big| \frac{3\,mol\,FeCl_2}{1\,mol\,KNO_3} \Big| \frac{126.8\,g\,FeCl_2}{1\,mol\,FeCl_2}\right]$

56.8 g − 52.7 g (used) = **4.1 g $FeCl_2$ in excess**

mass of HCl in excess: start $\boxed{40.0\,g} - \left[\frac{14.0\,g\,KNO_3}{} \Big| \frac{1\,mol\,KNO_3}{101.1\,g\,KNO_3} \Big| \frac{4\,mol\,HCl}{1\,mol\,KNO_3} \Big| \frac{36.5\,g\,HCl}{1\,mol\,HCl}\right]$

40.0 g − 20.2 g (used) = **19.8 g HCl in excess**

chemistry homework

Assignment #3: Hebden Questions #26-32 page 133-134
*Complete ALL assignments on a separate piece of paper and attach to your booklet when handing in at the end of the unit. Be sure to **clearly number each assignment with a heading.***

Part E: Percentage Yield & Percentage Purity

"theoretical yield"

Percentage Yield

Every summer, hundreds of young Canadians plant trees as part of the reforestation effort in BC. Imagine you and your group planted 5015 Douglas fir saplings on a mountainside on Vancouver Island. Five years later, a group of forestry surveyors checking for survival find that 4655 of these saplings have taken root and are growing. the percentage yield of your group's effort would be 93%.

"Actual Yield"

So far, we have been making the assumption that all reactions always go entirely to completion

Meaning that **all of the limiting reactant has been converted into product**, leaving only the excess reactant with none of the limiting reactant remaining at all.

In real life, this is not always the case. Like the tree planting example, many reactions complete themselves only **partially**.

Such reactions give only a partial percentage yield, less than 100% of the reactant are converted into products.

"Actual yield"

$$\text{Percentage Yield} = \frac{\text{mass product obtained}}{\text{mass product expected}} \times 100\%$$

"Theoretical Yield"

(the terms %yield is used to express how much of the product is actually obtained)

based on the limiting reactant.

The amount of product expected (calculated using stoichiometry) is commonly referred to as the Theoretical Yield.

Calculations of Yield

In any chemical reaction, the amount of product you get is called the chemical yield. The yield always differs from the amount you expect to form:

Theoretical yield = expected amount (from mass/amount of limiting reactant)

Actual yield = what is actually produced (given in the Q)

$$\boxed{\%\text{yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100\%}$$

could be mass, volume, moles, etc... must be same units!

Why does the actual yield differ from the theoretical yield?

There are many possible reasons. Some are acceptable and some aren't. Here are a few examples:

- Carelessness or sloppiness. Reactants improperly measured out or lost due to spills, etc. (human error)
- Product left behind in the reaction container when collected or transferred.
- Products may be contaminated. The mass of the impurity results in greater mass than expected.
  - Note: Water is frequently a source of error. Important to dry samples thoroughly before weighing.

experimental errors.

product is contaminated

NOTE: we can never make more product than expected *(unless we didn't make what we thought we did!)*

The actual yield of the PRODUCTS should be LESS than the theoretical yield.

3 Types of % Yield Calculations:

1. Find the percent yield, given the mass of reactant used and mass of product formed.
2. Find the mass of product formed, given the mass of reactant used and the percentage yield.
3. Find the mass of the reactant used, given the mass of product formed and the percentage yield.

Type 1 Problems: *Find the percent yield*, given the mass of reactant used and mass of product formed.

methane

When 15.0 g of $CH_{4(g)}$ is reacted with an excess of $Cl_{2(g)}$ according to the reaction:

actual yield

$CH_{4(g)} + Cl_{2(g)} \rightarrow CH_3Cl_{(g)} + HCl_{(g)}$ A total of $\boxed{29.7\text{ g of }CH_3Cl_{(g)}}$ is formed.

L.R. excess 29.7g

What is the percent yield of the reaction?

$$\%\text{ yield} = \frac{\text{actual}}{\text{theoretical}} \times 100 = \frac{29.7\cancel{g}\ CH_3Cl}{47.3\cancel{g}\ \cancel{CH_3Cl}} \times 100\% = \boxed{62.8\%}$$

Theoretical Yield (based on Limiting reactant)

amount Limiting → mol Limiting → mol prod. → amount product.

$$\frac{15.0g\ CH_4}{} \left| \frac{1\ mol\ CH_4}{16.0g\ CH_4} \right| \frac{1\ mol\ CH_3Cl}{1\ mol\ CH_4} \left| \frac{50.5g\ CH_3Cl}{1\ mol\ CH_3Cl} \right. = 47.3g\ CH_3Cl$$

PRACTICE *neutralization (gas formation)*

Example 2 A student carried out an experiment in which she completely reacted 45.8 g of potassium carbonate with an excess of hydrochloric acid. As a result, 46.3 g of potassium chloride were produced. What was the percentage yield of potassium chloride?

① Rxn + Balance K_2CO_3 + 2 HCl → 2 KCl + ____ H_2O + ____ CO_2

45.8g (Limiting) (excess) 46.3g

② Theoretical Yield mass of LR → mol L.R → mol Product → mass product.

$$\frac{45.8\text{g } K_2CO_3}{} \times \frac{1\text{ mol } K_2CO_3}{138.2\text{g } K_2CO_3} \times \frac{2\text{ mol KCl}}{1\text{ mol } K_2CO_3} \times \frac{74.6\text{g KCl}}{1\text{ mol KCl}} = 49.4\text{g KCl}$$

③ $\%\text{ yield} = \frac{\text{actual}}{\text{theoretical}} \times 100\% = \frac{46.3\text{g KCl}}{49.4\text{g KCl}} \times 100\% = \boxed{93.6\%}$

Type 2 Problems: *Find the mass of product* formed, given the mass of reactant used and the percentage yield.

Example 3 When a second student carried out the same reaction as above, 52.7 g of potassium chloride was obtained. Calculate the percentage yield. What most likely explains the result?

$\%\text{ yield} = \frac{\text{actual}}{\text{theoretical}} \times 100 = \frac{52.7\text{g KCl}}{49.4\text{g KCl}} \times 100\% = \boxed{107\%}$

∴ more product formed (7%) than expected (or possible). It is likely that the large mass (52.7g) is due to a wet (includes H_2O) or contaminated product.

PRACTICE

Example 4 If the reaction has a 76.0% yield, what mass of $K_2CO_{3(s)}$ is produced when 1.50 g of $KO_{2(s)}$ is reacted with an excess of $CO_{2(g)}$ according to the reaction:

asking for the actual yield.

① Balanced Rxn ✓ $4KO_{2(s)} + 2CO_{2(g)} \rightarrow 2K_2CO_{3(s)} + 3O_{2(g)}$

1.50g Limiting; excess; ?

✓ $\%\text{ yield} = \frac{\text{actual}}{\text{theoretical}}$

② Theoretical Yield amount LR → mol LR → mols prod. → mass prod.

$$\frac{1.50\text{g } KO_2}{} \times \frac{1\text{ mol } KO_2}{71.1\text{g } KO_2} \times \frac{2\text{ mol } K_2CO_3}{4\text{ mol } KO_2} \times \frac{138.2\text{g } K_2CO_3}{1\text{ mol } K_2CO_3} = 1.46\text{g } K_2CO_3$$

③ if $\%\text{ yield} = \frac{\text{actual}}{\text{theoretical}} \times 100$ then actual yield = (% yield)(theoretical)

decimal

$= (0.760)(1.46\text{g})$

actual yield = 1.11g K_2CO_3

Type 3 Problems: *Find the mass of the reactant* used, given the mass of product formed and the percentage yield

Example 5: *Recall: stoichiometry ratios assume 100% yield

If the reaction has a 58.0% yield, **what mass of CuO(s) is required** to make 10.0 g of Cu(s) according to the reaction:

$$2\,NH_3(aq) + 3\,CuO(s) \rightarrow N_2(g) + \underset{10.0\,g}{3\,Cu(s)} + 3\,H_2O(l)$$

① Based on stoichiometry (100%) yield, what mass of CuO is needed to theoretically produce 10.0 g of Cu?

$$\frac{10.0\,g\,Cu}{} \times \frac{1\,mol}{63.5\,g\,Cu} \times \frac{3\,mol\,CuO}{3\,mol\,Cu} \times \frac{79.5\,g\,CuO}{1\,mol\,CuO} = 12.52\,g\,CuO$$

② This mass is based on 100% yield... but we know the % yield is only 58.0%, so we must compensate:

If $\boxed{12.52\,g}$ CuO $\xrightarrow{100\%}$ 10.0 g Cu

Then $\boxed{21.6}$ g CuO $\xrightarrow{58\%}$ 10.0 g Cu

actual mass of CuO required $= \dfrac{12.52}{0.580} = \boxed{21.6\,g\,CuO}$

[% yield as decimal]

Sample Purity

When a sample is "impure" it means that only part of its mass is due to the pure substance.

e.g. If sample of NaCl is 75% pure, then **100.0 g of impure sample contains 75.0 g of pure NaCl.**

x % purity *means* x grams of ______ ____________ = 100 grams of ________ ________

From this equivalence statement, we get the conversion factors: $\dfrac{x\ g\text{ pure}}{100.0\ g\text{ impure}}$ or $\dfrac{100.0\ g\text{ impure}}{x\ g\text{ pure}}$

Example 1 A sample of potassium carbonate is 58.5% pure. What mass of sample contains 87.3 g of potassium carbonate? What mass of potassium carbonate is in 295.3 g of the sample?

Chem 11 **Chemical Reactions Review Assignment - Answers**

Please let me know if you have any questions or think you've found an error in the key. Study well!

1. a) C_8H_{16} + 12 O_2 → 8 CO_2 + 8 H_2O
   b) Cu + 2 H_2SO_4 → $CuSO_4$ + 2 H_2O + SO_2 (hard to balance using "the method" – sorry! Please feel free to omit this one)
   c) 2 Si_4H_{10} + 13 O_2 → 8 SiO_2 + 10 H_2O
   d) 4 NaPb + 4 C_2H_5Cl → $Pb(C_2H_5)_4$ + 3 Pb + 4 NaCl
   e) 3 $LiAlH_4$ + 4 BF_3 → 3 LiF + 3 AlF_3 + 2 B_2H_6
   f) 2 $C_{15}H_{31}NH$ + 46 O_2 → 30 CO_2 + 32 H_2O + N_2

2. a) N_2 + 3 H_2 → 2 NH_3 — Synthesis
   b) 2 CaO → 2 Ca + O_2 — Decomposition
   c) Mg + $CuSO_4$ → $MgSO_4$ + Cu — Single replacement
   d) H_3PO_4 + 3 KOH → K_3PO_4 + 3 H_2O — Neutralization
   e) 2 $Fe(NO_3)_3$ + 3 MgS → Fe_2S_3 + 3 $Mg(NO_3)_2$ — Double replacement
   f) 2 $C_{11}H_{21}SH$ + 35 O_2 → 22 CO_2 + 22 H_2O + 2 SO_2 — Hydrocarbon combustion

3. $Na_2S(aq)$ + $Zn(NO_3)_2(aq)$ → $ZnS(s)$ + 2 $NaNO_3(aq)$

4. a) Acid: A substances that can release a proton when dissolve to form aqueous solutions.
   b) Base: An ionic substance containing a hydroxide group. (e.g. NaOH, $Mg(OH)_2$, NH_4OH, etc)
   c) Salt: An ionic substance that is neither an acid nor a base.
   d) Activation Energy: The amount of energy needed to start a reaction.
   e) Enthalpy: the amount of energy stored in a chemical system.
   f) Exothermic Reaction: a reaction in which the amount of energy needed to break the bonds of the reactants is less than the amount of energy released when product bonds form.

5. a) The energy term appears on the products side.
   b) The reactant enthalpy is higher than the products; the axes must be properly labeled and (unlike in the text) I expect you to draw the activation energy correctly.

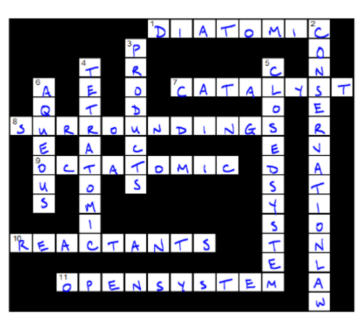
6. The change in enthalpy represents the difference between the enthalpy of products (*i.e.* final conditions) and the enthalpy of the reactants (*i.e.* initial conditions). This difference is positive in endothermic reactions because there is more stored energy in the system after the reaction completes while it is negative in exothermic reactions due to less heat being stored in the system after the reaction is over.

7. Endothermic reactions draw energy in from the surroundings to break the bonds of the reactants but they do not release as much energy from the newly formed product bonds. The net result is that more energy must be taken in than is returned to the surroundings.

8. Exothermic enthalpy changes are negative due to the final enthalpy being less than the initial enthalpy. ($\Delta H = H_f - H_i$).

9. Sulfur dioxide; SO_2 dissolves in the atmosphere to produce acid rain which the damages aquatic ecosystems, food crops and numerous structures. More energy is released when product bonds form than is consumed in breaking the reactant bonds.

10. Note: The question should refer to 2 e) and not to 2 b). The reaction is taking place in the aqueous phase. This means that while the reactants are part of the system, the water in which they are dissolved is not part of the system. Ask about this if you are unsure…



Chemistry 11 Chemical Reactions Review Assignment

If you want to earn full marks on each question, then you must show all of your mental steps wherever possible.

1. Balance the following reaction equations, taking care to show your balancing steps.

a) $C_8H_{16} + O_2 \rightarrow CO_2 + H_2O$

b) $Al + CuS \rightarrow Al_2S_3 + Cu$

c) $Si_4H_{10} + O_2 \rightarrow SiO_2 + H_2O$

d) $NaPb + C_2H_5Cl \rightarrow Pb(C_2H_5)_4 + Pb + NaCl$

e) $LiAlH_4 + BF_3 \rightarrow LiF + AlF_3 + B_2H_6$

f) $C_{15}H_{31}NH + O_2 \rightarrow CO_2 + H_2O + N_2$

2. Complete, balance and classify the following chemical reaction equations:

a) $N_2 + H_2 \rightarrow$

Type: ______________________________

b) $CaO \rightarrow$

Type: ______________________________

c) $Mg + CuSO_4 \rightarrow$

Type: ______________________________

d) $H_3PO_4 + KOH \rightarrow$

Type: ______________________________

e) $Fe(NO_3)_3\,(aq) + MgS\,(aq) \rightarrow$

Type: ______________________________

f) $C_{11}H_{21}SH + O_2 \rightarrow$

Type: ______________________________

3. Sodium sulfide and zinc nitrate solutions react when mixed. The product containing the sulfide group forms a precipitate. Write the balanced reaction equation and include the phases.

4. Carefully define the following terms:

a) ***Acid*** ______________________________

b) ***Base*** ______________________________

c) ***Salt*** ______________________________

d) ***Activation Energy*** ______________________________

____

e) ***Enthalpy*** ______________________________

____

f) ***Exothermic Reaction*** ______________________________

____

____

____

5. Consider the reaction: $2\ Al(s) + Fe_2O_3(s) \rightarrow 2\ Fe(s) + Al_2O_3(s)$; $\Delta H = -848$ kJ/mol.

a) Rewrite the reaction with the energy term as a reactant or product (whichever is appropriate).

b) Complete and fully label the following ***enthalpy*** versus ***reaction progress*** diagram.

6. What does the <u>change in enthalpy</u>, ΔH, represent? Explain.

____

____

7. Clearly explain why an endothermic reaction absorbs energy from the surroundings (describe the energy changes in your answer).

____

____

____

____

8. Why is the enthalpy change for an exothermic reaction always negative? You may refer to the potential energy (enthalpy) graph but be sure to answer using words.

____

____

____

____

9. The combustion of organic molecules that contain sulfur produces this gas: _______

What problem in the environment does this gas create? ____

____

____

Just for fun! Complete the crossword puzzle to review vocabulary.

Across

1 HOFBrINCl reminds us that these elements are __________ molecules. (8)

7 Speeds up a chemical reaction without being consumed. (8)

8 The part of the universe immediately outside of a system. (12)

9 Sulfur is an ___________ molecule. (9)

10 The chemicals whose bonds must be broken for a reaction to occur. (9)

11 A part of the universe being studied where something can enter or leave. (10)

Down

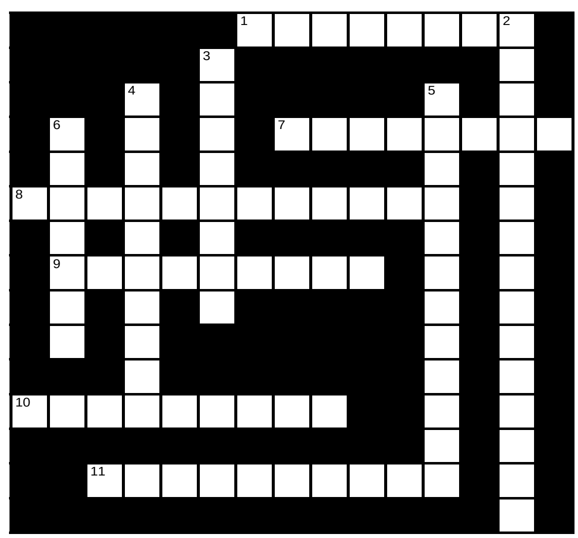
2 An experimentally observed law that states what is unchanged in a special set of circumstances. (15)

3 The chemicals whose bonds form as a chemical reaction occurs. (8)

4 Phosphorus is a ___________ molecule. (10)

5 A part of the universe being studied where nothing can enter or leave. (12)

6 Dissolved in water (7)



Chemistry 11 Stoichiometry Review Assignment

Name: ________________________________ **Date:**_______________ **Block:** _____

Answer the following practice questions on a separate page

Define the following terms:

1. Stoichiometry: quantitative relationships among substances as they participate in chemical reactions
2. Stoichiometric ratio: the molar ratio of substances in a chemical reaction (coefficients in a balanced chemical equation)
3. Limiting reactant the reactant in a chemical reaction is the substance that is totally consumed when the chemical reaction is complete. The amount of product formed is limited by this **reagent**, since the reaction cannot continue without it.
4. Excess reactant In a chemical reaction, reactants that are not use up when the reaction is finished are called excess reagents.
5. Percent yield is calculated to be the experimental **yield** divided by theoretical **yield** multiplied by 100%.

(Mole-Mole Conversions)

6. The combustion of the organic fuel, decane, is outlined in the chemical equation below. You must balance the equation in order to answer the subsequent questions a-c.

$$\_\_2\_\_C_{10}H_{22} + \_31\_O_2 \longrightarrow \_\_20\_\_CO_2 + \_\_22\_\_H_2O$$

a. How many moles of CO_2 are produced if 5.0 moles of $C_{10}H_{22}$ react with an excess of O_2?

b. How many moles of O_2 react with 0.75 moles of $C_{10}H_{22}$?

c. How many moles of O_2 would be required to produce 4.0 moles of H_2O?

a) $5.0 \text{ mol } C_{10}H_{22} \times \frac{20 \text{ mol } CO_2}{2 \text{ mol } C_{10}H_{22}} = \boxed{5.0 \times 10^1 \text{ mol } CO_2}$

b) $0.75 \text{ mol } C_{10}H_{22} \times \frac{31 \text{ mol } O_2}{2 \text{ mol } C_{10}H_{22}} = \boxed{12 \text{ mol } O_2}$

c) $4.0 \text{ mol } H_2O \times \frac{31 \text{ mol } O_2}{22 \text{ mol } H_2O} = \boxed{5.6 \text{ mol } O_2}$

7. Use the following equation to solve the problems below:

$$3\ SiO_2 + 4\ Al \longrightarrow 3\ Si + 2\ Al_2O_3$$

a. If 6.0 moles of SiO_2 react, how many moles of:

i. Al react?

ii. Si are produced?

iii. Al_2O_3 are produced?

b. If 2.5 moles of Al_2O_3 are produced, how many moles of:

i. Al react?

ii. SiO_2 react?

a) i) $\frac{6.0 \text{ mol } SiO_2 \;|\; 4 \text{ mol } Al}{\;|\; 3 \text{ mol } SiO_2} = \boxed{8.0 \text{ mol } Al}$

ii) $\frac{6.0 \text{ mol } SiO_2 \;|\; 3 \text{ mol } Si}{\;|\; 3 \text{ mol } SiO_2} = \boxed{6.0 \text{ mol } Si}$

iii) $\frac{6.0 \text{ mol } SiO_2 \;|\; 2 \text{ mol } Al_2O_3}{\;|\; 3 \text{ mol } SiO_2} = \boxed{4.0 \text{ mol } Al_2O_3}$

b) i) $\frac{2.5 \text{ mol } Al_2O_3 \;|\; 4 \text{ mol } Al}{\;|\; 2 \text{ mol } Al_2O_3} = \boxed{5.0 \text{ mol } Al}$

ii) $\frac{2.5 \text{ mol } Al_2O_3 \;|\; 3 \text{ mol } SiO_2}{\;|\; 2 \text{ mol } Al_2O_3} = \boxed{3.8 \text{ mol } SiO_2}$

(Mole-Mass / Mass-Mole Conversions)

8. $N_2 + 2O_2 \rightarrow N_2O_4$

   a) If 15.0g of N_2O_4 was produced, how many moles of O_2 were required?

15.0g N_2O_4	1 mol N_2O_4	2 mol O_2	= 0.326 mol O_2
	92.0g N_2O_4	1 mol N_2O_4	

   b) If 4.0×10^{-3} moles of oxygen reacted, how many grams of N_2 were needed?

4.0×10^{-3} mol O_2	1 mol N_2	28.0g N_2	= 5.6×10^{-2} g N_2
	2 mol O_2	1 mol N_2	

9. $Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag$ How many moles of Cu are needed to react with 3.50g of $AgNO_3$?

3.50g $AgNO_3$	1 mol $AgNO_3$	1 mol Cu	= 1.03×10^{-2} mol Cu
	169.9g $AgNO_3$	2 mol $AgNO_3$	

10. Mercury (II) oxide decomposes into mercury and oxygen gas.

   a) Write and balance the equation.

   $2HgO \rightarrow 2Hg + O_2$

   b) How many moles of mercury (II) oxide are needed to produce 125g of oxygen?

125g O_2	1 mol O_2	2 mol HgO	= 7.81 mol HgO
	32.0 g O_2	1 mol O_2	

   c) How many grams of mercury are produced if 24.5 moles of mercury (II) oxide decomposes?

24.5 mol HgO	2 mol Hg	200.6g Hg	= 4.91×10^3 g Hg
	2 mol HgO	1 mol Hg	

(Mass-Mass Conversions)

11. $Li_3N_{(s)} + 3H_2O_{(l)} \rightarrow NH_{3(g)} + 3LiOH_{(aq)}$

   a. What mass of lithium hydroxide are produced when 0.38g of lithium nitride react?

0.38g Li_3N	1 mol Li_3N	3 mol LiOH	23.9 g LiOH	= 0.79g LiOH
	34.7g Li_3N	1 mol Li_3N	1 mol LiOH	

   b. How many grams of lithium nitride would react with 4.05g of H_2O?

4.05g H_2O	1 mol H_2O	1 mol Li_3N	34.7g Li_3N	= 2.60g Li_3N
	18.0g H_2O	3 mol H_2O	1 mol Li_3N	

12. In the combustion of 54.50g of butane (C_4H_6), how many grams of CO_2 are produced? Write and balance the equation before solving.

   $2C_4H_6 + 11O_2 \rightarrow 8CO_2 + 6H_2O$

54.50g C_4H_6	1 mol C_4H_6	8 mol CO_2	44.0g CO_2	= 178g CO_2
	54.0g C_4H_6	2 mol C_4H_6	1 mol CO_2	

13. In the following **unbalanced** equation,

$\underline{4}\ FeS_2 + \underline{11}O_2 \rightarrow \underline{2}Fe_2O_3 + \underline{8}SO_2$

a) How many grams of iron (IV) sulphide are used when 9.0g of O_2 react?

9.0g O_2	1 mol O_2	4 mol FeS_2	120.0g FeS_2	= 12g FeS_2
	32.0g O_2	11 mol O_2	1 mol FeS_2	

b) What is the mass of iron (III) oxide produced when 25.0g of iron (IV) sulphide are used?

25.0g FeS_2	1 mol FeS_2	2 mol Fe_2O_3	159.6g Fe_2O_3	= 16.6g Fe_2O_3
	120.0g FeS_2	4 mol FeS_2	1 mol Fe_2O_3	

14. $Cu + 2AgNO_3 \rightarrow 2Ag + Cu(NO_3)_2$

How many grams of silver are produced when 36.92g of copper react?

36.92g Cu	1 mol Cu	2 mol Ag	107.9g Ag	= 125g Ag
	63.5g Cu	1 mol Cu	1 mol Ag	

15. ___$Al_2(SO_4)_3$ + ___$Ca(OH)_2$ → ___$Al(OH)_3$ + ___$CaSO_4$

Balance and answer the following questions.

$Al_2(SO_4)_3 + \underline{3}Ca(OH)_2 \rightarrow \underline{2}Al(OH)_3 + \underline{3}CaSO_4$

a. What mass of aluminum (III) hydroxide are produced if 165.7g of aluminum (III) sulfate react?

165.7g $Al_2(SO_4)_3$	1 mol $Al_2(SO_4)_3$	2 mol $Al(OH)_3$	78.0g $Al(OH)_3$	= 75.5g $Al(OH)_3$
	342.3g $Al_2(SO_4)_3$	1 mol $Al_2(SO_4)_3$		

b. How many grams of calcium hydroxide are needed to form 6.35g of calcium sulphate?

6.35g $CaSO_4$	1 mol $CaSO_4$	3 mol $Ca(OH)_2$	74.1g $Ca(OH)_2$	= 3.45g $Ca(OH)_2$
	136.2g $CaSO_4$	3 mol $CaSO_4$	1 mol $Ca(OH)_2$	

(Mass- Volume/ Volume-Volume Conversions)

16. Given the following equation:

$$3\,NO_{2\,(g)} + H_2O_{(l)} \longrightarrow 2\,HNO_{3\,(aq)} + NO_{(g)}$$ Assume STP

a. What mass of water is required to react with 15.5 L of Nitrogen dioxide?

b. What volume of Nitrogen monoxide would be produced from 100.0 g of water?

c. If 42.0 L of $NO_{(g)}$ is produced, what volume of $NO_{2\,(g)}$ reacted?

a.

15.5 L NO_2	1 mol NO_2	1 mol H_2O	18.0 g H_2O	= $\boxed{4.15\text{ g } H_2O}$
	22.4 L NO_2	3 mol NO_2	1 mol H_2O	

b.

100.0 g H_2O	1 mol H_2O	1 mol NO	22.4 L NO	= $\boxed{124\text{ L NO}}$
	18.0 g H_2O	1 mol H_2O	1 mol NO	

c.

42.0 L NO	1 mol NO	3 mol NO_2	22.4 L NO_2	= $\boxed{126\text{ L } NO_2}$
	22.4 L NO	1 mol NO	1 mol NO_2	

17. When Magnesium reacts with Nitric Acid, Hydrogen gas and aqueous Magnesium nitrate are formed. What volume of Hydrogen gas will be produced if 40.0 g of Magnesium is reacted with an excess of Nitric Acid?

$$Mg_{(s)} + 2HNO_{3\,(aq)} \longrightarrow Mg(NO_3)_{2\,(aq)} + H_{2\,(g)}$$

$$40.0\text{ g Mg} \times \frac{1\text{ mol Mg}}{24.3\text{ g Mg}} \times \frac{1\text{ mol } H_2}{1\text{ mol Mg}} \times \frac{22.4\text{ L } H_2}{1\text{ mol } H_2} = \boxed{36.9\text{ L } H_2}$$

18. The corrosion (rusting) of iron is represented as follows: (at STP)

$$3\,O_{2\,(g)} + 4\,Fe_{(s)} \longrightarrow 2\,Fe_2O_{3\,(s)}$$

a. What volume of Oxygen gas would be required to produce 16.0 g of Fe_2O_3?

b. What mass of Iron would be required to react with 10.0 L of O_2 gas?

$$16.0\text{ g } Fe_2O_3 \times \frac{1\text{ mol } Fe_2O_3}{159.6\text{ g } Fe_2O_3} \times \frac{3\text{ mol } O_2}{2\text{ mol } Fe_2O_3} \times \frac{22.4\text{ L } O_2}{1\text{ mol } O_2} = \boxed{3.37\text{ L } O_2}$$

b. $$10.0\text{ L } O_2 \times \frac{1\text{ mol } O_2}{22.4\text{ L } O_2} \times \frac{4\text{ mol Fe}}{3\text{ mol } O_2} \times \frac{55.8\text{ g Fe}}{1\text{ mol Fe}} = \boxed{33.2\text{ g Fe}}$$

19. Mercury (II) oxide decomposes when heated to produce liquid Mercury and Oxygen gas. What mass of Mercury (II) oxide would be required to produce 30.5 L of Oxygen gas? (Assume STP)

$$2HgO \longrightarrow 2Hg_{(l)} + O_{2\,(g)}$$

i) $$30.5\text{ L } O_2 \times \frac{1\text{ mol } O_2}{22.4\text{ L } O_2} \times \frac{2\text{ mol HgO}}{1\text{ mol } O_2} \times \frac{216.6\text{ g HgO}}{1\text{ mol HgO}} = \boxed{5.90\times10^2\text{ g HgO}}$$

ii) $$295\text{ g HgO} \times \frac{1\text{ mol HgO}}{216.6\text{ g HgO}} \times \frac{2\text{ mol Hg}}{2\text{ mol HgO}} \times \frac{200.6\text{ g Hg}}{1\text{ mol Hg}} \times \frac{1\text{ cm}^3\text{ Hg}}{13.6\text{ g Hg}} = \boxed{20.1\text{ cm}^3\text{ Hg}}$$

20. How many mL of 2.00M HNO3 is needed to consume 5.4g of aluminum?

$2Al + 6HNO_3 \rightarrow 2Al(HNO_3)_3 + 3H_2$

5.4g Al	1mol Al	6 mol HNO_3	
	27.0g Al	2 mol Al	= 0.60 molsHNO_3

$[HNO_3]$ = # mols ÷ volume So, Volume = mols ÷ $[HNO_3]$ =0.60mol ÷2M = 0.3 L (x 1000)= **3.0×10^2 mL HNO_3**

21. 20mL of HCl is needed to consume 2.8g Fe. What is the concentration of HCl?

__2Fe + _6_HCl → _2_$FeCl_3$ + _3_H_2

2.8g Fe	1mol Fe	6 mol HCl	
	55.8g Fe	2 mol Fe	=0.15 mol HCl

[HCl] = n ÷V = 0.15mol HCl ÷0.02L = 7.5M HCl

22. What mass of copper will react with 10.0mL of 12.0M nitric acid?

Cu + _4_HNO_3 → __$Cu(NO_3)_2$ + _2_NO_2 + _2_H_2O

$[HNO_3]$ = # mols ÷ volume So mols HNO_3 = 12.0 M x 0.01 L = 0.12 mol HNO_3

0.12 mol HNO_3	1 mol Cu	63.5 g Cu	
	4 mol HNO_3	1 mol Cu	= 1.91 g Cu

Name: Key Block:_______ Date:______________

Chemistry 11 **Limiting Reagents and Percent Yield Key** Assignment

1. O_2 is limiting.
2. $Mg(OH)_2$ is limiting.
3. H_2SO_4 is limiting.
4. NaCl is in excess.
5. 12g of $CrCl_3$
6. 15.5g SO_3
7. 44.2g Fe
8. 27.3g N_2
9. 22.9g NaCl
10. a) $Pb(NO_3)_2 + 2NaI \rightarrow 2NaNO_3 + PbI_2$
    b) 8.51g $NaNO_3$
    c) NaI
    d) 8.4g $Pb(NO_3)_2$ would be left over.
11. 42% yield
12. 49.1% yield
13. 81.6% yield
14. a) 20.00g $FeCl_2$
    b) 20.0% yield
15. a) 22.2g CS_2
    b) 2.1g SO_2 left over.
16. 0.279g $BaBr_2$
17. a) 21.1g SiF_4
    b) 8.03g left unused.
    c) 34.2% yield

REVIEW: Limiting Reagents and Percent Yield

Answer all questions on separate paper and report all answers to the correct number of sig figs.

1. Identify the limiting reactant when 1.22g of O_2 reacts with 1.05g of H_2 to produce water.
2. Identify the limiting reactant when5.87g of $Mg(OH)_2$ reacts with 12.84g of HCl to form $MgCl_2$ and water.
3. Identify the limiting reactant when 6.33g of sulphuric acid reacts with 5.92g of sodium hydroxide to produce sodium sulphate and water.
4. Identify the reactant in excess if 6.25g of silver nitrate reacts with 4.12g of sodium chloride to form sodium nitrate and silver chloride.
5. If 4.1g of Cr is heated with 9.3g of Cl_2 what mass of $CrCl_3$ will be produced?
6. What mass of sulphur trioxide is produced when 12.4g of sulphur dioxide is reacted with 3.45g of oxygen gas?
7. If 21.4g of aluminum is reacted with 91.3g of iron (III) oxide, the products will be aluminum oxide and iron. What mass of iron will be produced?
8. If 41.6g of N_2O_4 reacts with 20.8g of N_2H_4, the products will be nitrogen gas and water. What mass of nitrogen will be produced?
9. What mass of NaCl will be produced by the reaction of 58.7g of NaI with 29.4g of Cl_2?
10. a. Write the balanced equation for the reaction of lead (II) nitrate with sodium iodide to form sodium nitrate and lead (II) iodide:

    b. If I start with 25.0 grams of lead (II) nitrate and 15.0 grams of sodium iodide, how many grams of sodium nitrate can be formed?

    c. What is the limiting reagent in the reaction?

    d. How much of the excess reagent will be left over from the reaction?
11. You calculate that using a certain amount of beryllium and hydrochloric acid you can produce 10.7g of beryllium chloride. You perform the experiment and only collect 4.5g. What was the percent yield for the reaction?

12. Determine the percent yield for the reaction between 45.9g of NaBr and excess chlorine gas to produce 12.8g of NaCl and an unknown quantity of bromine gas.

13. Determine the percent yield for the reaction between 44.5g of zinc sulphide and 13.3g of oxygen, if 18.4g of zinc oxide is recovered with an unknown amount of sulphur dioxide.

14. A reaction was carried out according to the following equation:

$$FeBr_2 + 2\ KCl \rightarrow FeCl_2 + 2\ KBr$$

a. What is the theoretical yield of iron (II) chloride if 34.00 grams of iron (II) bromide was used in the reaction with excess potassium chloride?

b. What is the percent yield of iron (II) chloride if the actual yield is 4.00 grams?

15. a. What mass of $CS_{2(s)}$ is produced when 17.5 g of $C_{(s)}$ are reacted with 39.5 g of $SO_{2(g)}$ according to the equation: $5\ C_{(s)} + 2\ SO_{2(g)} \rightarrow CS_{2(s)} + 4\ CO_{(g)}$?

b. What mass of the excess reactant will be left over?

16. If 0.250 g of $Ba(OH)_{2(s)}$ is mixed with 15.0 mL of 0.125 M $HBr_{(aq)}$, what mass of $BaBr_{2(aq)}$ can be formed?

$$Ba(OH)_{2(s)} + 2\ HBr_{(aq)} \rightarrow BaBr_{2(aq)} + 2\ H_2O_{(l)}$$

17. The reaction $SiO_{2(s)} + 4\ HF_{(g)} \rightarrow SiF_{4(g)} + 2\ H_2O_{(g)}$ produces 2.50 g of $H_2O_{(g)}$ when 12.20g of $SiO_{2(s)}$ is treated with a small excess of $HF_{(g)}$.

a. What mass of $SiF_{4(g)}$ is formed?

b. What mass of $SiO_{2(s)}$ is left unreacted if only 2.50g of H_2O is formed?

c. What is the percent yield of the $H_2O_{(g)}$?