Unit 6: Reactions and Stoichiometry
(Link to Prentice Hall Text: Chapters 7, 8 & 9)

Name:____

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A. Representing Change with Equations

Parts of a Chemical Equation

$$1Al\ (s) + Fe_2O_3\ (s) \xrightarrow{\text{glycerin}} Al_2O_3\ (\ell) + 2\ Fe\ (\ell) + \text{Heat}$$

Common Notation Used in Equations:

(s) - chemical is a solid

(ℓ) - chemical is a liquid

(g) - chemical is a gas

(aq) - chemical is part of a solution with water

Heat May Be a Product or a Reactant

When heat is a reactant, the reaction is said to be endothermic (heat is added).

When heat is a product, the reaction is said to be exothermic (heat is escaping).

B. Balancing Chemical Reactions

Rules for Balancing Equations

- ✓ Never change the formula (subscripts can't change).
- ✓ Only change the coefficients!
- ✓ The coefficients should be in the simplest whole number ratio.
- ✓ If there is no coefficient written, a coefficient of on is assumed

Tips for Balancing Equations

Balance all other atoms then balance oxygen and lastly hydrogen
If you can treat polyatomic ions as if they were atoms.
Use a pencil! It is okay to make mistakes.

Equation Balancing Practice: The Applied Law of Conservation of Matter

1. [2] H_2 + [ ] O_2 → [ ] H_2O

2. [3] H_2 + [ ] N_2 → [2] NH_3

3. [2] Al_2O_3 → [4] Al + [3] O_2

4. [2] $KClO_3$ → [2] KCl + [3] O_2

5. [ ] S_8 + [8] O_2 → [8] SO_2

6. [2] C_2H_6 + [7] O_2 → [4] CO_2 + [6] H_2O

7. [ ] $Al_2(SO_4)_3$ + [3] $Ca(OH)_2$ → [2] $Al(OH)_3$ + [3] $CaSO_4$

8. [ ] P_4 + [5] O_2 → [2] P_2O_5

9. [16] Ag + [ ] S_8 → [8] Ag_2S

10. [2] Al + [3] Br_2 → [2] $AlBr_3$

11. [4] Cr + [3] O_2 → [2] Cr_2O_3

12. [2] C_2H_2 + [5] O_2 → [4] CO_2 + [2] H_2O

13. [2] C_6H_6 + [15] O_2 → [12] CO_2 + [6] H_2O

14. [2] Na + [2] H_2O → [2] $NaOH$ + [ ] H_2

15. [2] AlI_3 + [3] $HgCl_2$ → [2] $AlCl_3$ + [3] HgI_2

16. [3] $Ca(OH)_2$ + [2] H_3PO_4 → [ ] $Ca_3(PO_4)_2$ + [6] H_2O

17. [3] $AgNO_3$ + [ ] K_3PO_4 → [ ] Ag_3PO_4 + [3] KNO_3

18. [ ] C_3H_8 + [5] O_2 → [3] CO_2 + [4] H_2O

Use the law of conservation of mass to determine the missing reactant in the equation given below.

1. $2NaHCO_3$ → $Na_2CO_3 + H_2O$ + _CO_2__
2. $BaCl_2 + K_2CO_3$ → _$2KCl$_ + $BaCO_3$
3. $2C_6H_6$ + _$15O_2$__ → $12CO_2 + 6H_2O$
4. $CaCO_3$ → CaO + _CO_2_

1. Given the equation $PbO_2 \rightarrow PbO + O_2$, how many grams of oxygen will be produced if 47.8g of PbO_2 decompose to form 44.6g of PbO and oxygen gas?

47.8 g - 44.6 g = 3.2 g of O_2

2. How many grams of Fe are needed to react with 8.0g of O_2 to produce 28.9g of Fe_3O_4 according to the equation $3Fe + 2O_2 \rightarrow Fe_3O_4$?

28.9 g - 8.0 g = 20.9 g of Fe

C. Five Patterns of Chemical Reactivity

Type 1 - Synthesis "Building Up"

Two or more reactant molecules combine together to make one product.

2 Na + Cl_2 → 2 **NaCl**
2 Li + Br_2 → 2 **LiBr**

Type 2 -Decomposition "Breaking Down"

One **reactant** molecule breaks into simpler **product m**olecules.

2 **NaCl** → 2 Na + Cl_2
2 **LiBr** → 2 Li + Br_2

Type 3 - Single Replacement

One **element** replaces another in a compound. The more active metal loses its electrons and gains a partner.

2 **Fe** + 3 **Cu**Cl_2 → 3 **Cu** + 2 **Fe**Cl_3	(Fe replaces Cu)
2 **Na** + 2 **H**OH (*or H_2O*) → $\mathbf{H_2}$ + 2 **Na**OH	(Na replaces H – metal replacement)
Ni + 2 **H**Cl → $\mathbf{H_2}$ + **Ni**Cl_2	(Ni replaces H – metal replacement)
2 $\mathbf{F_2}$ + 2 H_2**O** → $\mathbf{O_2}$ + 4 H**F**	(F replaces O – nonmetal replacement)

Practice Predicting Products for Single Replacement Reactions

Use Table J to determine if a reaction occurs. Predict the products. Balance the reaction.

1. ___Ca + ___$CuSO_4$ → $CaSO_4$ + Cu
2. ___Mg + ___$Ba(NO_3)_2$ → No Reaction
3. _2__Al + __6_HCl → 2 $AlCl_3$ + 3 H_2
4. ___Cu + ___NaCl → No reaction
5. ___Mg + __2_HCl → $MgCl_2$ + H_2
6. ___F_2 + __2_NaI → 2 NaF + I_2
7. ___Br_2 + ___CaI_2 → $CaBr_2$ + I_2

Type 4 - Double Replacement

Ionic Compounds trade partners.

CaCl_2(aq) + 2 **Ag**NO_3(aq) → **Ca**$(NO_3)_2$(aq) + 2 **Ag**Cl(s)

Na_2 SO_4(aq) + **Ba**Cl_2(aq) → 2 **Na**Cl(aq) + **Ba**SO_4(s)

Pb$(NO_3)_2$(aq) + 2 **Li**OH(aq) → **Pb**$(OH)_2$(s) + 2 **Li**NO_3(aq)

Practice Predicting Products for Double Replacement Reactions.

Predict the products. Balance the reaction.

1. _2__$FeBr_3$ + _3__$CaCrO_4$ → $Fe_2(CrO_4)_3$ + 3 $CaBr_2$
2. ___$AgNO_3$ + ___NaCl → $NaNO_3$ + AgCl
3. _2__NH_4OH + ___$Co(ClO_3)_2$ → 2 NH_4ClO_3 + $Co(OH)_2$
4. ___Na_2S + ___$Fe(NO_3)_2$ → FeS + 2 $NaNO_3$
5. ___Na_2SO_4 + ___$Ba(NO_3)_2$ → $BaSO_4$ + 2 $NaNO_3$
6. ___NaBr +___$AgNO_3$ → AgBr + $NaNO_3$
7. ___K_2CO_3 + ___$Ca(NO_3)_2$ → 2 KNO_3 + $CaCO_3$
8. ___ $(NH_4)_2SO_4$ + ___$BaCl_2$ → $BaSO_4$ + 2 NH_4Cl
9. ___$Ba(NO_3)_2$ +___ K_2CrO_4 → 2 KNO_3 + $BaCrO_4$
10. _2__NaOH + ___$CaCl_2$ → $Ca(OH)_2$ + 2 NaCl

Type 5 – Combustion

Oxygen is always a reactant, carbon dioxide and water are products.

CH_4 + 2 **O_2** → C**O_2** + 2 H_2**O** (burning natural gas)

C_3H_8 + 5 **O_2** → 3 C**O_2** + 4 H_2**O** (burning propane)

Practice Predicting Products of Combustion Reactions

Predict the products. Balance the reaction.

1. _2__C_2H_6 +_7__ O_2 → 4 CO_2 + 6 H_2O
2. _2__C_4H_{10} + _13__O_2 → 8 CO_2 + 10 H_2O
3. ___CH_2O + ___O_2 → CO_2 + H_2O

Categorization Practice!

Write balanced chemical reactions for the following reactions. Categorize the reaction as Synthesis (S), Decomposition (D), Single Replacement (SR), Double Replacement (DR).

1. Ammonia (NH_3) reacts with hydrogen chloride to form ammonium chloride.

   $NH_3 + HCl \rightarrow NH_4Cl$ Synthesis

2. Calcium carbonate decomposes upon heating to form calcium oxide and carbon dioxide.

   $CaCO_3 \rightarrow CaO + CO_2$ Decomposition

3. Barium oxide reacts with water to form barium hydroxide.

   $BaO + H_2O \rightarrow Ba(OH)_2$ Synthesis

4. Acetaldehyde (CH_3CHO) decomposes to form methane (CH_4) and carbon monoxide.

   $CH_3CHO \rightarrow CH_4 + CO$ Decomposition

5. Zinc reacts with copper(II) nitrate to form zinc nitrate and copper.

   $Zn + Cu(NO_3)_2 \rightarrow Zn(NO_3)_2 + Cu$ Single Replacement

6. Calcium sulfite decomposes when heated to form calcium oxide and sulfur dioxide.

   $CaSO_3 \rightarrow CaO + SO_2$ Decomposition

7. Iron reacts with sulfuric acid (H_2SO_4 to form iron(II) sulfate and hydrogen gas.

   $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$ Single Replacement

8. Phosgene, $COCl_2$, is formed when carbon monoxide reacts with chlorine gas.

   $CO + Cl_2 \rightarrow COCl_2$ Synthesis

9. Manganese(VII) iodide decomposes when exposed to light to form manganese and iodine.

   $2\ MnI_7 \rightarrow 2\ Mn + 7\ I_2$ Decomposition

10. Dinitrogen pentoxide reacts with water to produce nitric acid (HNO_3).

    $N_2O_5 + H_2O \rightarrow 2\ HNO_3$ Synthesis

11. Silver nitrate reacts with iron(III) bromide to form iron(III) nitrate and silver bromide

    $3\ AgNO_3 + FeBr_3 \rightarrow Fe(NO_3)_3 + 3\ AgBr$ Double Replacement

Molar Mass:

Synonyms for Molar Mass: formula mass, formula weight, molecular mass, gram-formula mass, g.f.m., molecular weight and $\mathcal{M}$

Find the molar masses of the following compounds:

1) NaBr

Na: 1 × 23.0 = 23.0 g/mol
Br: 1 × 79.9 = + 79.9 g/mol
102.9 g/mol

2) $PbSO_4$

Pb: 1 × 207.2 = 207.2 g/mol
S: 1 × 32.1 = 32.1 g/mol
O: 4 × 16.0 = + 64.0 g/mol
303.3 g/mol

3) $Ca(OH)_2$

Ca: 1 × 40.1 = 40.1 g/mol
O: 2 × 16.0 = 32.0 g/mol
H: 2 × 1.0 = + 2.0 g/mol
74.1 g/mol

4) Na_3PO_4

Na: 3 × 23.0 = 69.0 g/mol
P: 1 × 31.0 = 31.0 g/mol
O: 4 × 16.0 = + 64.0 g/mol
164.0 g/mol

5) $(NH_4)_2CO_3$

N: 2 × 14.0 = 28.0 g/mol
H: 8 × 1.0 = 8.0 g/mol
C: 1 × 12.0 = 12.0 g/mol
O: 3 × 16.0 = + 48.0 g/mol
96.0 g/mol

6) $C_6H_{12}O_6$

C: 6 × 12.0 = 72.0 g/mol
H: 12 × 1.0 = 12.0 g/mol
O: 6 × 16.0 = + 96.0 g/mol
180.0 g/mol

7) $Fe_3(PO_4)_2$

Fe: 3 × 55.8 = 167 g/mol
P: 2 × 31.0 = 62.0 g/mol
O: 8 × 16.0 = + 128. g/mol
357. g/mol

8) $(NH_4)_2S$

N: 2 × 14.0 = 28.0 g/mol
H: 8 × 1.0 = 8.0 g/mol
S: 1 × 32.1 = + 32.1 g/mol
68.1 g/mol

9) $Zn(C_2H_3O_2)_2$

Zn: 1 × 65.4 = 65.4 g/mol
C: 4 × 12.0 = 48.0 g/mol
H: 6 × 1.0 = 6.0 g/mol
O: 4 × 16.0 = + 64.0 g/mol
183.4 g/mol

10) AgF

Ag: 1 × 107.9 = 107.9 g/mol
F: 1 × 19.0 = + 19.0 g/mol
126.9 g/mol

Percent Composition: The percent by mass of each element in a compound

Formula: $\frac{\text{mass of part}}{\text{mass of whole}} \cdot 100\% = \%\text{ composition}$

Find the percent mass of each atom in the following compounds

1. $C_6H_{12}O_6$

$M = 180.0\ g/mol$

$\%C = \frac{(6 \cdot 12\ g/mol)}{180.\ g/mol} \cdot 100\% = 40.0\%$

$\%H = \frac{(12 \cdot 1.0\ g/mol)}{180.\ g/mol} \cdot 100\% = 6.67\%$

$\%O = \frac{(6 \cdot 16.0\ g/mol)}{180.\ g/mol} \cdot 100\% = 53.3\%$

2. $Ca(NO_3)_2$

$M = 164.1\ g/mol$

$\%Ca = \frac{(1 \times 40.1\ g/mol)}{164.1\ g/mol} \cdot 100\% = 24.4\%$

$\%N = \frac{(2 \times 14.0\ g/mol)}{164.1\ g/mol} \cdot 100\% = 17.1\%$

$\%O = \frac{(6 \times 16.0\ g/mol)}{164.1\ g/mol} \cdot 100\% = 58.5\%$

3. $(NH_4)_2SO_4$

$M = 132.1\ g/mol$

$\%N = \frac{(2 \cdot 14\ g/mol)}{(132.1\ g/mol)} \cdot 100\% = 21.2\%$

$\%H = \frac{(8 \cdot 1.0\ g/mol)}{132.1\ g/mol} \cdot 100\% = 6.1\%$

$\%S = \frac{(1 \cdot 32.0\ g/mol)}{132.1\ g/mol} \cdot 100\% = 24.2\%$

$\%O = \frac{(4 \cdot 16.0\ g/mol)}{132.1\ g/mol} \cdot 100\% = 48.4\%$

4. CH_3COOH

$M = 60.0\ g/mol$

$\%C = \frac{(2 \cdot 12.0\ g/mol)}{60.0\ g/mol} \cdot 100\% = 40\%$

$\%H = \frac{(4 \cdot 1.0\ g/mol)}{60.0\ g/mol} \cdot 100\% = 6.67\%$

$\%O = \frac{(2 \cdot 16.0\ g/mol)}{60.0\ g/mol} \cdot 100\% = 53.3\%$

5. $Fe(ClO)_3$

$M = 210.3\ g/mol$

$\%Fe = \frac{(1 \cdot 55.8\ g/mol)}{210.3\ g/mol} \cdot 100\% = 26.5\%$

$\%Cl = \frac{(3 \cdot 35.5\ g/mol)}{210.3\ g/mol} \cdot 100\% = 50.6\%$

$\%O = \frac{(3 \cdot 16.0\ g/mol)}{210.3\ g/mol} \cdot 100\% = 22.8\%$

Big Numbers and Chemistry

At the most fundamental level, the chemist needs a unit that describes a very large quantity.

One of the most well-known numbers in the study of chemistry is number of units in a mole. The number of units in a mole is called Avogadro's number (named after the Italian physicist). The mole is defined as the number of atoms in 12.0 grams of ^{12}C. As you can tell from the equality below, the mole is also a conversion factor.

6.02×10^{23} molecules = 1 mole

The mole is the currency of choice for a chemist. It is a currency that allows them to convert between a number of molecules and the mass of those molecules.

Bakers and grocers use a similar idea to represent eggs. If you were asked to by a dozen eggs how many eggs would you buy?

12 eggs

If you were asked to buy a gross of eggs how many eggs would you buy?

1 dozen = 12 eggs

1 gross = 12 dozen

$$1\ \text{gross} \cdot \frac{12\ \text{dozen}}{1\ \text{gross}} \cdot \frac{12\ \text{eggs}}{1\ \text{dozen}} = 144\ \text{eggs}$$

If you were asked to buy 5 moles of eggs how many eggs would you buy?

1 mol eggs = 6.02×10^{23} eggs

$$5\ \text{mol eggs} \cdot \frac{6.02 \times 10^{23}\ \text{eggs}}{1\ \text{mol eggs}} = 3.01 \times 10^{24}\ \text{eggs}$$

When performing mole calculations you must use dimensional analysis. Remember the three key questions for solving conversion problems.

-What do I want to find?

-What have I been given in the problem?

-What conversion factors can I use to calculate the necessary value?

Mole Map

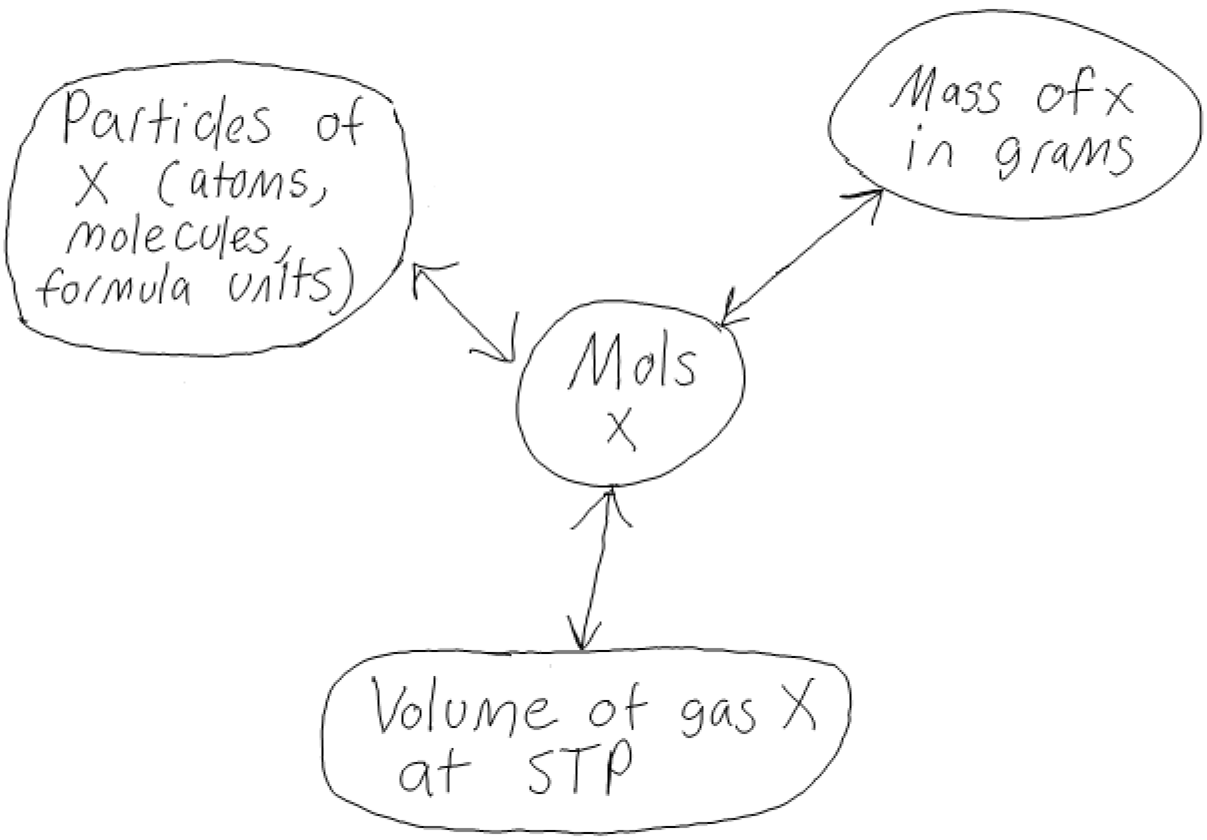
Equivalency Statement:

1 mol X = molar mass in grams of X

1mol X = 6.02×10^{23} X's

1mol X = 22.4 L of X if and only if X is a gas at STP

STP = standard temperature and pressure 0 °C and 1 atm.



Mole Conversion Practice Problems

Convert the following values using dimensional analysis. You must show all work!

1. How many grams are in 4.2 moles of Mg?

$$4.2 \text{ mols Mg} \cdot \frac{24.3 \text{ g Mg}}{1 \text{ mol Mg}} = 102.06 \text{ g Mg}$$

2. How many grams are in 2.3 moles of calcium fluoride?

$$2.3 \text{ mols } CaF_2 \cdot \frac{78 \text{ g } CaF_2}{1 \text{ mol } CaF_2} = 179.4 \text{ g } CaF_2$$

3. How many moles are in 345 grams of oxygen gas?

$$345 \text{ g } O_2 \cdot \frac{1 \text{ mol } O_2}{32 \text{ g } O_2} = 10.8 \text{ mol } O_2$$

4. How many moles are in 12.34 x 10^{24} atoms of argon?

$$12.34 \times 10^{24} \text{ atoms Ar} \cdot \frac{1 \text{ mol Ar}}{6.02 \times 10^{23} \text{ atoms Ar}} = 20.5 \text{ mol Ar}$$

5. How many liters would 2.3 moles of nitrogen gas occupy at STP?

$$2.3 \text{ mols } N_2 \cdot \frac{22.4 \text{ L } N_2}{1 \text{ mol } N_2} = 51.52 \text{ L } N_2$$

6. How many particles are in 56g of methane (CH_4)

$$56 \text{ g } CH_4 \cdot \frac{1 \text{ mol } CH_4}{16 \text{ g } CH_4} \cdot \frac{6.02 \times 10^{23} \text{ particles } CH_4}{1 \text{ mol } CH_4} = 2.11 \times 10^{24} \text{ particles } CH_4$$

7. How many grams would be found in 39.0L of Helium gas at STP?

$$39.0 \text{ L He} \cdot \frac{1 \text{ mol He}}{22.4 \text{ L He}} \cdot \frac{4 \text{ g He}}{1 \text{ mol He}} = 6.96 \text{ g He}$$

8. 1 gram of liquid water at STP has an approximate volume of 1 mL. What is the volume of 1 gram of gaseous water at STP?

$$1 \text{ g } H_2O \cdot \frac{1 \text{ mol } H_2O}{18 \text{ g } H_2O} \cdot \frac{22.4 \text{ L } H_2O}{1 \text{ mol } H_2O} = 1.24 \text{ L } H_2O$$

9. What is the volume of each of the following gases at STP?

a. 7.6 mol Ar

$$7.6 \text{ mol Ar} \cdot \frac{22.4 \text{ L Ar}}{1 \text{ mol Ar}} = 170.24 \text{ L Ar}$$

b. 0.44 grams C_2H_6

$$0.44 \text{ g } C_2H_6 \cdot \frac{1 \text{ mol } C_2H_6}{30 \text{ g } C_2H_6} \cdot \frac{22.4 \text{ L } C_2H_6}{1 \text{ mol } C_2H_6} = 0.329 \text{ L } C_2H_6$$

c. 1.20 x 10^{23} molcules of O_2

$$1.20 \times 10^{23} \text{ molecules } O_2 \cdot \frac{1 \text{ mol } O_2}{6.02 \times 10^{23} \text{ molecules } O_2} \cdot \frac{22.4 \text{ L } O_2}{1 \text{ mol } O_2} = 4.47 \text{ L } O_2$$

10. A chocolate turtle has approximately 2.5 g of sugar ($C_{12}H_{22}O_{11}$) in it. One mole of sugar molecules equals 342 g. How many moles of sugar are in one chocolate turtle?

$$2.5 \text{ g sugar} \cdot \frac{1 \text{ mol sugar}}{342 \text{ g sugar}} = 7.31 \times 10^{-3} \text{ mol sugar}$$

How many molecules of sugar are in one chocolate turtle?

$$7.31 \times 10^{-3} \text{ mol sugar} \cdot \frac{6.02 \times 10^{23} \text{ molecules sugar}}{1 \text{ mol sugar}} = 4.40 \times 10^{21} \text{ molecules sugar}$$

How many atoms of carbon are found in the sugar from one chocolate turtle?

$$4.40 \times 10^{21} \text{ molecules sugar} \cdot \frac{12 \text{ atoms C}}{1 \text{ molecule sugar}} = 5.28 \times 10^{22} \text{ atoms C}$$

Review

Empirical Formula: Chemical formula that represents the simplest whole number ratio of atoms in a compounds. (All of the subscripts have a greatest common factor of one)

Molecular Formula: Chemical formula that represents the actual number of atoms in a molecule. Usually for covalent compounds.

Finding an Empirical Formula from Percent Composition

During the yearly lab cleaning, you come across an unlabeled sample. You send away a small portion of the chemical for percent composition analysis. The results come back as:

58.8 % C
9.8 % H
31.4 % 0

Chemical formulas are ratios of atoms or moles of atoms. To solve a chemical analysis problem you must convert mass percent of each element to a molar ratio of each element.

Step 1 Assume your unknown sample has a mass of 100 grams.

Assume 100g sample

Convert % to g

58.8 % C

$0.588 \cdot 100g = 58.8g$ C

9.8 % H → 9.8 g H

31.4% O → 31.4 g O

Step 2 Convert the mass of each element to moles of each element using the molar mass.

$58.8g\,C \cdot \frac{1\,mol\,C}{12\,g\,C} = 4.9$ mol C

$9.8g\,H \cdot \frac{1\,mol\,H}{1\,g\,H} = 9.8$ mol H

$31.4g\,O \cdot \frac{1\,mol\,O}{16\,g\,O} = 1.963$ mol O

Step 3 Divide the moles of each element by the smallest number of moles

$\frac{4.9\,mol\,C}{1.963\,mol} = 2.5$ $\quad \frac{9.8\,mol\,H}{1.963\,mol} = 5$ $\quad \frac{1.963\,mol\,O}{1.963\,mol} = 1$

Step 4 if necessary, multiply the molar ratio by small whole number coefficients in order to obtain the **simplest whole number** ratio.

$C_{2.5}H_5O \xrightarrow{x2} C_5H_{10}O_2$ ← Empirical formula

What is the Molecular Identity of the Unknown?

We found that the empirical formula for the unknown substance was $C_5H_{10}O_2$. Its gram molecular mass is 204 g/mol. What is the molecular formula of the unknown substance?

$$\frac{M}{\text{Empirical formula mass}} = \text{Multiplying factor} \qquad \frac{204\ \text{g/mol}}{(5\cdot 12\ \text{g/mol} + 10\cdot 1\ \text{g/mol} + 2\cdot 16\ \text{g/mol})} = 2$$

$$C_5H_{10}O_2 \xrightarrow{\times 2} C_{10}H_{20}O_4 \leftarrow \text{molecular formula}$$

You Decide: Empirical or Molecular?

Are the following formulas empirical or molecular?

a. S_2Cl_2	Molecular formula	b. $C_6H_{10}O_4$	Molecular formula
c. Na_2SO_3	Empirical formula	d. $C_5H_{10}O_5$	Molecular formula
e. $C_{17}H_{19}NO_3$	Empirical formula	f. $(NH_4)_2CO_3$	Empirical formula

You try it now!

Model your work based on the above example.

1. What is the molecular formula for each compound? The empirical formula and molar mass are given below.

   a. CH_2O, 90 g/mol

   $$\frac{90\ \text{g/mol}}{30\ \text{g/mol}} = 3 \qquad CH_2O \xrightarrow{\times 3} C_3H_6O_3$$

   b. HgCl, 472.2 g/mol

   $$\frac{472.2\ \text{g/mol}}{236.09\ \text{g/mol}} = 2 \qquad HgCl \xrightarrow{\times 2} Hg_2Cl_2$$

   c. $C_3H_5O_2$, 146 g/mol

   $$\frac{146\ \text{g/mol}}{72\ \text{g/mol}} = 2 \qquad C_3H_5O_2 \xrightarrow{\times 2} C_6H_{10}O_4$$

d. Vitamin C has an empirical formula of $C_3H_4O_3$ and a molecular mass of 176 amu. What is its molecular formula?

$$176\ \text{amu} \cdot \frac{1\ \text{g/mol}}{1\ \text{amu}} = 176\ \text{g/mol}$$

$$\frac{176\ \text{g/mol}}{88\ \text{g/mol}} = 2 \qquad C_3H_4O_3 \xrightarrow{\times 2} C_6H_8O_6$$

2. Determine the molecular formula for each compound:

a. 94.1 % O and 5.9 % H; molar mass = 34 g

Assume 100 gram sample

94.1% O → 94.1 g O   5.9% H → 5.9 g H

$$94.1\ \text{g O} \cdot \frac{1\ \text{mol O}}{16\ \text{g O}} = 5.88\ \text{mol O} \qquad 5.9\ \text{g H} \cdot \frac{1\ \text{mol H}}{1\ \text{g H}} = 5.9\ \text{mol H}$$

$$\frac{5.88\ \text{mol O}}{5.88\ \text{mol}} = 1 \qquad \frac{5.9\ \text{mol H}}{5.88\ \text{mol}} = 1$$

Empirical formula: HO

$$\frac{34\ \text{g/mol}}{17\ \text{g/mol}} = 2 \qquad HO \xrightarrow{\times 2} \boxed{H_2O_2}$$

b. 40.0% C, 6.6 % H and 53.4 % O; molar mass = 120 g

Assume 100g sample

40.0% C → 40.0g C

6.6% H → 6.6 g H

53.4% O → 53.4g O

$40.0\,g\,C \cdot \frac{1\ mol\ C}{12\ g\ C} = 3.33\ mol\ C$

$6.6\,g\,H \cdot \frac{1\ mol\ H}{1\ g\ H} = 6.6\ mol\ H$

$53.4\,g\,O \cdot \frac{1\ mol\ O}{16\ g\ O} = 3.34\ mol\ O$

$\frac{3.33\ mol\ C}{3.33\ mol} = 1$ $\frac{6.6\ mol\ H}{3.33\ mol} = 2$ $\frac{3.34\ mol\ O}{3.33\ mol} = 1$

Empirical formula = CH_2O

$\frac{120\ g/mol}{30\ g/mol} = 4$ $CH_2O \xrightarrow{\times 4} \boxed{C_4H_8O_4}$

3. What is the empirical formula of a compound that is 58.80% barium, 13.75% sulfur, and 27.45% oxygen by mass?

Assume 100g sample

58.80% Ba → 58.80g Ba

13.75% S → 13.75 g S

27.45% O → 27.45 g O

$58.80\text{g Ba} \cdot \frac{1 \text{ mol Ba}}{137.33 \text{g Ba}} = 0.428 \text{ mol Ba}$

$13.75 \text{g S} \cdot \frac{1 \text{ mol S}}{32 \text{ g S}} = 0.430 \text{ mol S}$

$27.45 \text{g O} \cdot \frac{1 \text{ mol O}}{16 \text{ g O}} = 1.716 \text{ mol O}$

$\frac{0.428 \text{ mol Ba}}{0.428 \text{ mol}} = 1$ $\frac{0.430 \text{ mol S}}{0.428 \text{ mol}} = 1$ $\frac{1.716 \text{ mol O}}{0.428 \text{ mol}} = 4$

Empirical formula $BaSO_4$

4. Caffeine, a stimulant found in coffee, tea, and chocolate, contains 49.48% carbon, 5.15% hydrogen, 28.87% nitrogen, and 16.49% oxygen by mass, and has a molecular mass of 194.2 g/mol. Determine the molecular formula of caffeine.

Assume 100g sample

49.48% C → 49.48 g C   5.15% H → 5.15 g H

28.87% N → 28.87 g N   16.49% O → 16.49 g O

$$49.48\text{ g C} \cdot \frac{1\text{ mol C}}{12\text{ g C}} = 4.12\text{ mol C}$$

$$5.15\text{ g H} \cdot \frac{1\text{ mol H}}{1\text{ g H}} = 5.15\text{ mol H}$$

$$28.87\text{ g N} \cdot \frac{1\text{ mol N}}{14\text{ g N}} = 2.06\text{ mol N}$$

$$16.49\text{ g O} \cdot \frac{1\text{ mol O}}{16\text{ g O}} = 1.03\text{ mol O}$$

$$\frac{4.12\text{ mol C}}{1.03\text{ mol}} = 4 \quad \frac{5.15\text{ mol H}}{1.03\text{ mol}} = 5 \quad \frac{2.06\text{ mol N}}{1.03\text{ mol}} = 2$$

$$\frac{1.03\text{ mol O}}{1.03\text{ mol}} = 1 \quad C_4H_5N_2O \text{ Empirical formula}$$

$$\frac{194.2\text{ g/mol}}{97\text{ g/mol}} = 2 \quad C_4H_5N_2O \xrightarrow{\times 2} \boxed{C_8H_{10}N_4O_2}$$

Stoichiometry!

1. If 156.0 grams of potassium metal reacts with excess water, then how many grams of potassium hydroxide are formed? What volume of hydrogen gas, in liters, is formed at STP ?

__2__ K (s) + _____ H_2O (l) → __2__ KOH (aq) + _____ H_2 (g)

$$156.0\,g\,K \cdot \frac{1\,mol\,K}{39.1\,g\,K} \cdot \frac{2\,mol\,KOH}{2\,mol\,K} \cdot \frac{56\,g\,KOH}{1\,mol\,KOH} = \boxed{223\,g\,KOH}$$

$$156.0\,g\,K \cdot \frac{1\,mol\,K}{39.1\,g\,K} \cdot \frac{1\,mol\,H_2}{2\,mol\,K} \cdot \frac{22.4\,L\,H_2}{1\,mol\,H_2} = \boxed{44.68\,L\,H_2}$$

2. Given the unbalanced decomposition reaction of baking soda:

__2__ $NaHCO_3$ (s) → ____ Na_2CO_3 (s) + ____ CO_2 (g) + ___ H_2O (g)

How many grams of each product are produced by the decomposition of 42.0 grams of baking soda?

$$42.0\,g\,NaHCO_3 \cdot \frac{1\,mol\,NaHCO_3}{84\,g\,NaHCO_3} \cdot \frac{1\,mol\,CO_2}{2\,mol\,NaHCO_3} \cdot \frac{44\,g\,CO_2}{1\,mol\,CO_2} = \boxed{11\,g\,CO_2}$$

$$42.0\,g\,NaHCO_3 \cdot \frac{1\,mol\,NaHCO_3}{84\,g\,NaHCO_3} \cdot \frac{1\,mol\,H_2O}{2\,mol\,NaHCO_3} \cdot \frac{18\,g\,H_2O}{1\,mol\,H_2O} = \boxed{4.5\,g\,H_2O}$$

$$42.0\,g\,NaHCO_3 \cdot \frac{1\,mol\,NaHCO_3}{84\,g\,NaHCO_3} \cdot \frac{1\,mol\,Na_2CO_3}{2\,mol\,NaHCO_3} \cdot \frac{106\,g\,Na_2CO_3}{1\,mol\,Na_2CO_3} = \boxed{26.5\,g\,Na_2CO_3}$$

3. The unbalanced combustion reaction of butane gas in excess oxygen produces carbon dioxide gas and water vapor: C_4H_{10} (l) + O_2 (g) → CO_2 (g) + H_2O (l). Starting with 11.6 grams of butane, how many grams of carbon dioxide gas and water vapor are formed at STP?

$$2\,C_4H_{10} + 13\,O_2 \rightarrow 8\,CO_2 + 10\,H_2O$$

$$11.6\,g\,C_4H_{10} \cdot \frac{1\,mol\,C_4H_{10}}{58.1\,g\,C_4H_{10}} \cdot \frac{8\,mol\,CO_2}{2\,mol\,C_4H_{10}} \cdot \frac{44\,g\,CO_2}{1\,mol\,CO_2} = \boxed{35.1\,g\,CO_2}$$

$$11.6\,g\,C_4H_{10} \cdot \frac{1\,mol\,C_4H_{10}}{58.1\,g\,C_4H_{10}} \cdot \frac{10\,mol\,H_2O}{2\,mol\,C_4H_{10}} \cdot \frac{18\,g\,H_2O}{1\,mol\,H_2O} = \boxed{18.0\,g\,H_2O}$$

4. The catalytic decomposition of hydrogen peroxide is:

$\underline{\ 2\ }\ H_2O_2\,(aq) \rightarrow \underline{\ 2\ }\ H_2O\,(l) + \underline{\quad}\ O_2\,(g)$

How many moles of water and oxygen are produced by the decomposition of 68.0 grams of hydrogen peroxide?

$$68.0\ g\ H_2O_2 \cdot \frac{1\ mol\ H_2O_2}{34\ g\ H_2O_2} \cdot \frac{2\ mol\ H_2O}{2\ mol\ H_2O_2} = \boxed{2\ mol\ H_2O}$$

$$68.0\ g\ H_2O_2 \cdot \frac{1\ mol\ H_2O_2}{34\ g\ H_2O_2} \cdot \frac{1\ mol\ O_2}{2\ mol\ H_2O_2} = \boxed{1\ mol\ O_2}$$

5. The Haber reaction produces ammonia, an important nitrogenous compound needed to make plant fertilizers. The unbalanced reaction is: $N_2\,(g) + H_2\,(g) \rightarrow NH_3\,(g)$. If 170.0 grams of ammonia are produced, then how many grams of nitrogen gas and hydrogen gas are needed? How many molecules of each reactant are needed?

$N_2\,(g) + 3\ H_2\,(g) \rightarrow 2\ NH_3\,(g).$

$$170.0\ g\ NH_3 \cdot \frac{1\ mol\ NH_3}{17\ g\ NH_3} \cdot \frac{1\ mol\ N_2}{2\ mol\ NH_3} \cdot \frac{28\ g\ N_2}{1\ mol\ N_2} = \boxed{140\ g\ N_2}$$

$$170.0\ g\ NH_3 \cdot \frac{1\ mol\ NH_3}{17\ g\ NH_3} \cdot \frac{1\ mol\ N_2}{2\ mol\ NH_3} \cdot \frac{6.02\times10^{23}\ molecules\ N_2}{1\ mol\ N_2} = \boxed{3.01\times10^{24}\ molecules\ N_2}$$

$$170.0\ g\ NH_3 \cdot \frac{1\ mol\ NH_3}{17\ g\ NH_3} \cdot \frac{3\ mol\ H_2}{2\ mol\ NH_3} \cdot \frac{2\ g\ H_2}{1\ mol\ H_2} = \boxed{30\ g\ H_2}$$

$$170.0\ g\ NH_3 \cdot \frac{1\ mol\ NH_3}{17\ g\ NH_3} \cdot \frac{3\ mol\ H_2}{2\ mol\ NH_3} \cdot \frac{6.02\times10^{23}\ molecules\ H_2}{1\ mol\ H_2} = \boxed{9.03\times10^{24}\ molecules\ H_2}$$

6. Given the unbalanced reaction: $H_{2\,(g)} + O_{2\,(g)} \rightarrow HOH_{\,(g)}$. What volume of hydrogen gas is needed to completely react 17.8 L of oxygen gas?

$2\ H_2 + O_2 \rightarrow 2\ H_2O$

$$17.8\ L\ O_2 \cdot \frac{1\ mol\ O_2}{22.4\ L\ O_2} \cdot \frac{2\ mol\ H_2}{1\ mol\ O_2} \cdot \frac{22.4\ L\ H_2}{1\ mol\ H_2} = \boxed{35.6\ L\ H_2}$$

7. The unbalanced synthesis reaction between aluminum metal and oxygen is:

$$Al_{(s)} + O_{2(g)} \rightarrow Al_2O_{3(s)}.$$

If 6.02×10^{25} molecules of aluminum oxide are produced, then how many grams of aluminum metal was used?

$$4\ Al + 3\ O_2 \rightarrow 2\ Al_2O_3$$

$$6.02 \times 10^{25}\ \text{formula units}\ Al_2O_3 \cdot \frac{1\ mol\ Al_2O_3}{6.02 \times 10^{23}\ \text{formula units}\ Al_2O_3} \cdot \frac{4\ mol\ Al}{2\ mol\ Al_2O_3} \cdot \frac{27\ g\ Al}{1\ mol\ Al} = \boxed{5400\ g\ Al}$$

8. __4__ NH_3 + __3__ O_2 → __2__ N_2 + __6__ H_2O

Based on the unbalanced reaction above:

a. How many moles of oxygen react with 0.23 moles of NH_3?

$$0.23\ mol\ NH_3 \cdot \frac{3\ mol\ O_2}{4\ mol\ NH_3} = \boxed{0.173\ mol\ O_2}$$

b. How many grams of water will be produced if 0.55 moles of oxygen react?

$$0.55\ mol\ O_2 \cdot \frac{6\ mol\ H_2O}{3\ mol\ O_2} \cdot \frac{18\ g\ H_2O}{1\ mol\ H_2O} = \boxed{19.8\ g\ H_2O}$$

c. How many grams of nitrogen gas will be produced if 12.6 grams of ammonia react?

$$12.6\ g\ NH_3 \cdot \frac{1\ mol\ NH_3}{17\ g\ NH_3} \cdot \frac{2\ mol\ N_2}{4\ mol\ NH_3} \cdot \frac{28\ g\ N_2}{1\ mol\ N_2} = \boxed{10.4\ g\ N_2}$$

Limiting Reactants

Limiting reactant is the *reactant that runs out first, the other reactant is called "excess"*
When the limiting reactant is exhausted, then the reaction stops.

Example Problem:

10.0g of aluminum reacts with 35.0 grams of chlorine gas to produce aluminum chloride. Which reactant is limiting, which is in excess, and how much product is produced? How much of the excess reactant is left over?

Limiting Reactant Problems

1. Sodium metal reacts with oxygen to produce sodium oxide. If 5.00 g of sodium reacted with 5.00 grams of oxygen, how many grams of product is formed? $4Na + O_2 \rightarrow 2Na_2O$

$5.00\,g\,O_2 \cdot \frac{1\,mol\,O_2}{32\,g\,O_2} \cdot \frac{2\,mol\,Na_2O}{1\,mol\,O_2} \cdot \frac{62\,g\,Na_2O}{1\,mol\,Na_2O} =$ ~~19.4 g Na_2O formed~~

$5.00\,g\,Na \cdot \frac{1\,mol\,Na}{23\,g\,Na} \cdot \frac{2\,mol\,Na_2O}{4\,mol\,Na} \cdot \frac{62\,g\,Na_2O}{1\,mol\,Na_2O} = 6.74\,g\,Na_2O$ formed ✓

Na is the limiting reactant. O_2 is the excess reactant.

2. How many grams of solid are formed when 10.0 g of lead reacts with 10.0 g of phosphoric acid?

_3_ Pb+ _2_ $H_3PO_4 \rightarrow Pb_3(PO_4)_{2\,(s)}$ + _3_ $H_{2\,(g)}$

$10.0\,g\,Pb \cdot \frac{1\,mol\,Pb}{207.2\,g\,Pb} \cdot \frac{1\,mol\,Pb_3(PO_4)_2}{3\,mol\,Pb} \cdot \frac{811\,g\,Pb_3(PO_4)_2}{1\,mol\,Pb_3(PO_4)_2} = 13\,g\,Pb_3(PO_4)_2$ formed ✓

$10.0\,g\,H_3PO_4 \cdot \frac{1\,mol\,H_3PO_4}{98\,g\,H_3PO_4} \cdot \frac{1\,mol\,Pb_3(PO_4)_2}{2\,mol\,H_3PO_4} \cdot \frac{811\,g\,Pb_3(PO_4)_2}{1\,mol\,Pb_3(PO_4)_2} =$ ~~41.4 g $Pb_3(PO_4)_2$ formed~~

Pb is limiting.

3. If 25 g of aluminum was added to 90 g of HCl, what mass of H_2 will be produced?

$2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$

$25\,g\,Al \cdot \frac{1\,mol\,Al}{27\,g\,Al} \cdot \frac{3\,mol\,H_2}{2\,mol\,Al} \cdot \frac{2\,g\,H_2}{1\,mol\,H_2} =$ ~~2.78 g H_2~~

$90\,g\,HCl \cdot \frac{1\,mol\,HCl}{36.5\,g\,HCl} \cdot \frac{3\,mol\,H_2}{6\,mol\,HCl} \cdot \frac{2\,g\,H_2}{1\,mol\,H_2} = 2.46\,g\,H_2$ ✓

HCl is limiting

4. If you have 20 g of N_2 and 5.0 g of H_2, which is the limiting reagent?

__N_2 + _3_ H_2 → _2_ NH_3

$$20\,g\,N_2 \cdot \frac{1\,mol\,N_2}{28\,g\,N_2} \cdot \frac{2\,mol\,NH_3}{1\,mol\,N_2} \cdot \frac{17\,g\,NH_3}{1\,mol\,NH_3} = 24.3\,g\,NH_3$$ ✓

$$5.0\,g\,H_2 \cdot \frac{1\,mol\,H_2}{2\,g\,H_2} \cdot \frac{2\,mol\,NH_3}{3\,mol\,H_2} \cdot \frac{17\,g\,NH_3}{1\,mol\,NH_3} = ~~28.3\,g\,NH_3~~$$

N_2 is limiting

5. What mass of aluminum oxide is formed when 10.0 g of Al is burned in 20.0 g of O_2?

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

$$10.0\,g\,Al \cdot \frac{1\,mol\,Al}{27\,g\,Al} \cdot \frac{2\,mol\,Al_2O_3}{4\,mol\,Al} \cdot \frac{102\,g\,Al_2O_3}{1\,mol\,Al_2O_3} = 18.9\,g\,Al_2O_3$$ ✓

$$20.0\,g\,O_2 \cdot \frac{1\,mol\,O_2}{32\,g\,O_2} \cdot \frac{2\,mol\,Al_2O_3}{3\,mol\,O_2} \cdot \frac{102\,g\,Al_2O_3}{1\,mol\,Al_2O_3} = ~~42.5\,g\,Al_2O_3~~$$

6. When C_3H_8 burns in oxygen, CO_2 and H_2O are produced. If 15.0 g of C_3H_8 reacts with 60.0 g of O_2, how many grams of CO_2 is produced? What mass of each reactant is left over?

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

$$15.0\,g\,C_3H_8 \cdot \frac{1\,mol\,C_3H_8}{44\,g\,C_3H_8} \cdot \frac{3\,mol\,CO_2}{1\,mol\,C_3H_8} \cdot \frac{44\,g\,CO_2}{1\,mol\,CO_2} = 45\,g\,CO_2$$ ✓

$$60.0\,g\,O_2 \cdot \frac{1\,mol\,O_2}{32\,g\,O_2} \cdot \frac{3\,mol\,CO_2}{5\,mol\,O_2} \cdot \frac{44\,g\,CO_2}{1\,mol\,CO_2} = ~~49.5\,g\,CO_2~~$$

C_3H_8 is limiting, there is zero grams of C_3H_8 left over.

$$15.0\,g\,C_3H_8 \cdot \frac{1\,mol\,C_3H_8}{44\,g\,C_3H_8} \cdot \frac{5\,mol\,O_2}{1\,mol\,C_3H_8} \cdot \frac{32\,g\,O_2}{1\,mol\,O_2} = 54.5\,g\,O_2 \text{ used}$$

Original Mass of excess reactant − Mass of excess reactant used = Mass of excess reactant left over

$60.0\,g\,O_2 - 54.5\,g\,O_2$ used = 5.5 g O_2 left over

7.When 10.0 g of copper was reacted with 60.0 g of silver nitrate solution. How many grams of silver are produced? How much of each reactant is left over?(Calculate the amount in grams)
$Cu + 2\,AgNO_3 \rightarrow Cu(NO_3)_2 + 2\,Ag$.

$$10.0\text{ g Cu} \cdot \frac{1\text{ mol Cu}}{63.6\text{ g Cu}} \cdot \frac{2\text{ mol Ag}}{1\text{ mol Cu}} \cdot \frac{108\text{ g Ag}}{1\text{ mol Ag}} = 34.0\text{ g Ag}$$ ✓

$$60.0\text{ g AgNO}_3 \cdot \frac{1\text{ mol AgNO}_3}{170\text{ g AgNO}_3} \cdot \frac{2\text{ mol Ag}}{2\text{ mol AgNO}_3} \cdot \frac{108\text{ g Ag}}{1\text{ mol Ag}} = \text{~~38.1 g Ag~~}$$

Cu is limiting, there will be <u>zero grams</u> of Cu left.

$$10.0\text{ g Cu} \cdot \frac{1\text{ mol Cu}}{63.6\text{ g Cu}} \cdot \frac{2\text{ mol AgNO}_3}{1\text{ mol Cu}} \cdot \frac{170\text{ g AgNO}_3}{1\text{ mol AgNO}_3} = 53.5\text{ g AgNO}_3$$

Original Mass of excess reactant − Mass of excess reactant used = Mass of excess reactant left over

$60.0\text{ g } AgNO_3 - 53.5\text{ g } AgNO_3$ used = <u>$6.5\text{ g } AgNO_3$</u> left over