Mass Relationships in Chemical Reactions

Chapter 3

Micro World atoms & molecules → Macro World grams

Atomic mass is the mass of an atom in atomic mass units (amu)

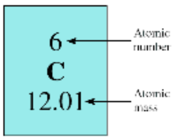
By definition:
1 atom ^{12}C "weighs" 12 amu

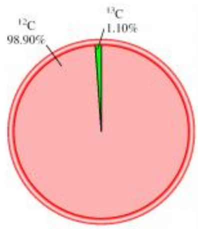
On this scale

^{1}H = 1.008 amu

^{16}O = 16.00 amu

The ***average atomic mass*** is the weighted average of all of the naturally occurring isotopes of the element.





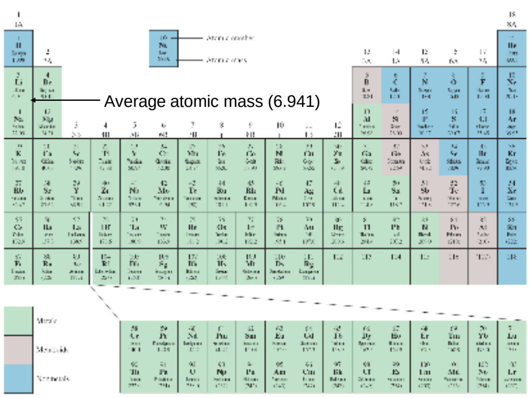
Naturally occurring lithium is:

7.42% ^{6}Li (6.015 amu)

92.58% ^{7}Li (7.016 amu)

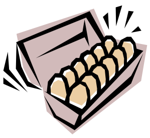
Average atomic mass of lithium:

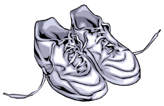
$$\frac{7.42 \times 6.015 + 92.58 \times 7.016}{100} = 6.941 \text{ amu}$$



The Mole (mol): A unit to count numbers of particles

Dozen = 12





Pair = 2

The ***mole (mol)*** is the amount of a substance that contains as many elementary entities as there are atoms in exactly 12.00 grams of ^{12}C

$$1 \text{ mol} = N_A = 6.0221367 \times 10^{23}$$

Avogadro's number (N_A)

Molar mass is the mass of 1 mole of eggs / shoes / marbles / atoms in grams

1 mole ^{12}C atoms = 6.022 x 10^{23} atoms = 12.00 g

1 ^{12}C atom = 12.00 amu

1 mole ^{12}C atoms = 12.00 g ^{12}C

1 mole lithium atoms = 6.941 g of Li

For any element
atomic mass (amu) = molar mass (grams)

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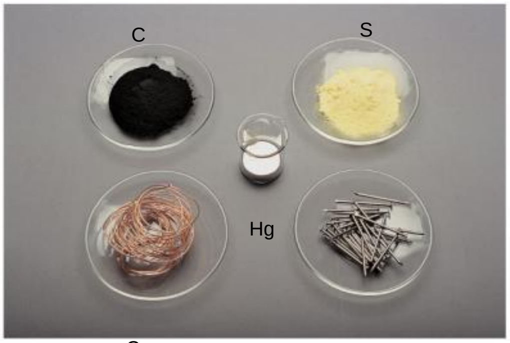
One Mole of:



Cu   Fe

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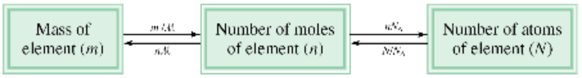
$$\frac{1\ ^{12}\text{C}\ \cancel{\text{atom}}}{12.00\ \text{amu}} \times \frac{12.00\ \text{g}}{6.022 \times 10^{23}\ ^{12}\text{C}\ \cancel{\text{atoms}}} = \frac{1.66 \times 10^{-24}\ \text{g}}{1\ \text{amu}}$$

1 amu = 1.66 x 10^{-24} g or 1 g = 6.022 x 10^{23} amu



$\mathcal{M}$ = molar mass in g/mol

N_A = Avogadro's number

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How many atoms are in 0.551 g of potassium (K) ?

1 mol K = 39.10 g K

1 mol K = 6.022 x 10^{23} atoms K

$$0.551\ \cancel{\text{g K}} \times \frac{\cancel{1\ \text{mol K}}}{39.10\ \cancel{\text{g K}}} \times \frac{6.022 \times 10^{23}\ \text{atoms K}}{\cancel{1\ \text{mol K}}} =$$

8.49 x 10^{21} atoms K

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Molecular mass (or molecular weight) is the sum of the atomic masses (in amu) in a molecule.

SO_2

1S	32.07 amu
2O	+ 2 x 16.00 amu
SO_2	64.07 amu

For any molecule
molecular mass (amu) = molar mass (grams)

1 molecule SO_2 = 64.07 amu

1 mole SO_2 = 64.07 g SO_2

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How many H atoms are in 72.5 g of C_3H_8O ?

1 mol C_3H_8O = (3 x 12.01) + (8 x 1.008) + 16.00
= 60.09 g C_3H_8O

1 mol C_3H_8O molecules = 8 mol H atoms

1 mol H = 6.022 x 10^{23} atoms H

$$72.5\ \cancel{\text{g C}_3\text{H}_8\text{O}} \times \frac{\cancel{1\ \text{mol C}_3\text{H}_8\text{O}}}{\cancel{60.09\ \text{g C}_3\text{H}_8\text{O}}} \times \frac{\cancel{8\ \text{mol}}\ \text{H atoms}}{\cancel{1\ \text{mol C}_3\text{H}_8\text{O}}} \times \frac{6.022 \times 10^{23}\ \text{H atoms}}{\cancel{1\ \text{mol H atoms}}} =$$

5.82 x 10^{24} atoms H

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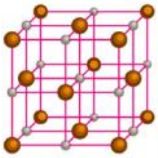
Formula mass is the sum of the atomic masses (in amu) in a formula unit of an ionic compound.



NaCl

1Na	22.99 amu
1Cl	+ 35.45 amu
NaCl	58.44 amu

For any ionic compound
formula mass (amu) = molar mass (grams)

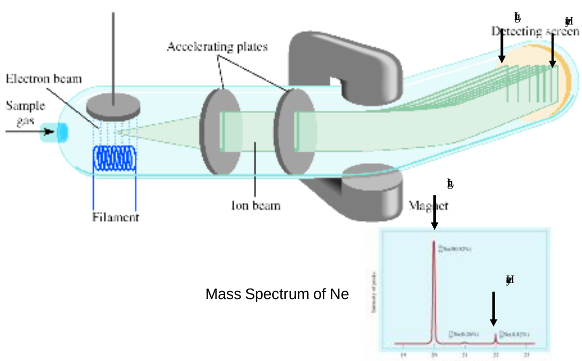
1 formula unit NaCl = 58.44 amu
1 mole NaCl = 58.44 g NaCl

What is the formula mass of $Ca_3(PO_4)_2$?

1 formula unit of $Ca_3(PO_4)_2$

3 Ca	3 x 40.08
2 P	2 x 30.97
8 O	+ 8 x 16.00
	310.18 amu

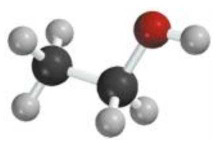
Mass Spectrometer



Percent composition of an element in a compound =

$$\frac{n \text{ x molar mass of element}}{\text{molar mass of compound}} \text{ x } 100\%$$

n is the number of moles of the element in 1 mole of the compound



C_2H_6O

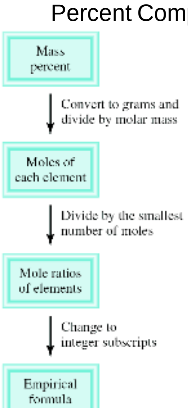
$$\%C = \frac{2 \text{ x } (12.01 \text{ g})}{46.07 \text{ g}} \text{ x } 100\% = 52.14\%$$

$$\%H = \frac{6 \text{ x } (1.008 \text{ g})}{46.07 \text{ g}} \text{ x } 100\% = 13.13\%$$

$$\%O = \frac{1 \text{ x } (16.00 \text{ g})}{46.07 \text{ g}} \text{ x } 100\% = 34.73\%$$

52.14% + 13.13% + 34.73% = 100.0%

Percent Composition and Empirical Formulas



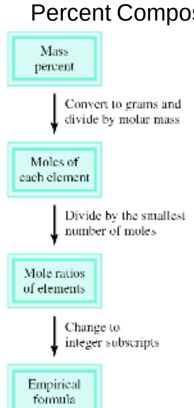
Determine the empirical formula of a compound that has the following percent composition by mass:
K 24.75, Mn 34.77, O 40.51 percent.

$$n_K = 24.75 \text{ g K} \text{ x } \frac{1 \text{ mol K}}{39.10 \text{ g K}} = 0.6330 \text{ mol K}$$

$$= 34.77 \text{ g Mn} \text{ x } \frac{1 \text{ mol Mn}}{54.94 \text{ g Mn}} = 0.6329 \text{ mol Mn}$$

$$n_O = 40.51 \text{ g O} \text{ x } \frac{1 \text{ mol O}}{16.00 \text{ g O}} = 2.532 \text{ mol O}$$

Percent Composition and Empirical Formulas



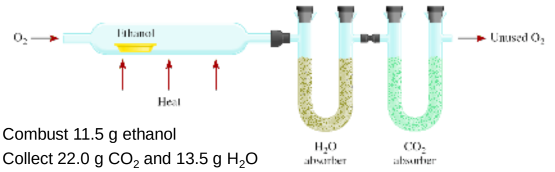
$n_K = 0.6330$, $n_{Mn} = 0.6329$, $n_O = 2.532$

$$K : \frac{0.6330}{0.6329} \approx 1.0$$

$$Mn : \frac{0.6329}{0.6329} = 1.0$$

$$O : \frac{2.532}{0.6329} \approx 4.0$$

$KMnO_4$



Combust 11.5 g ethanol

Collect 22.0 g CO_2 and 13.5 g H_2O

g CO_2 ⟶ mol CO_2 ⟶ mol C ⟶ g C 6.0 g C = 0.5 mol C

g H_2O ⟶ mol H_2O ⟶ mol H ⟶ g H 1.5 g H = 1.5 mol H

g of O = g of sample – (g of C + g of H) 4.0 g O = 0.25 mol O

Empirical formula $C_{0.5}H_{1.5}O_{0.25}$

Divide by smallest subscript (0.25)

Empirical formula C_2H_6O

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A process in which one or more substances is changed into one or more new substances is a ***chemical reaction***

A ***chemical equation*** uses chemical symbols to show what happens during a chemical reaction

reactants ⟶ products

3 ways of representing the reaction of H_2 with O_2 to form H_2O

Two hydrogen molecules + One oxygen molecule ⟶ Two water molecules

$2H_2 + O_2 \longrightarrow 2H_2O$

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How to "Read" Chemical Equations

$2\ Mg + O_2 \longrightarrow 2\ MgO$

2 atoms Mg + 1 molecule O_2 makes 2 formula units MgO

2 moles Mg + 1 mole O_2 makes 2 moles MgO

48.6 grams Mg + 32.0 grams O_2 makes 80.6 g MgO

NOT

2 grams Mg + 1 gram O_2 makes 2 g MgO

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Balancing Chemical Equations

1. Write the **correct** formula(s) for the reactants on the left side and the **correct** formula(s) for the product(s) on the right side of the equation.

Ethane reacts with oxygen to form carbon dioxide and water

$C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$

2. Change the numbers in front of the formulas (***coefficients***) to make the number of atoms of each element the same on both sides of the equation. Do not change the subscripts.

$2C_2H_6$ **NOT** C_4H_{12}

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Balancing Chemical Equations

3. Start by balancing those elements that appear in only one reactant and one product.

$C_2H_6 + O_2 \longrightarrow CO_2 + H_2O$ start with C or H but not O

2 carbon on left 1 carbon on right multiply CO_2 by 2

$C_2H_6 + O_2 \longrightarrow 2CO_2 + H_2O$

6 hydrogen on left 2 hydrogen on right multiply H_2O by 3

$C_2H_6 + O_2 \longrightarrow 2CO_2 + 3H_2O$

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Balancing Chemical Equations

4. Balance those elements that appear in two or more reactants or products.

$C_2H_6 + O_2 \longrightarrow 2CO_2 + 3H_2O$ multiply O_2 by $\frac{7}{2}$

2 oxygen on left 4 oxygen (2x2) + 3 oxygen (3x1) = 7 oxygen on right

$C_2H_6 + \frac{7}{2}O_2 \longrightarrow 2CO_2 + 3H_2O$ remove fraction multiply both sides by 2

$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$

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Balancing Chemical Equations

5. Check to make sure that you have the same number of each type of atom on both sides of the equation.

$2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$

4 C (2 x 2)	4 C
12 H (2 x 6)	12 H (6 x 2)
14 O (7 x 2)	14 O (4 x 2 + 6)

Reactants	Products
4 C	4 C
12 H	12 H
14 O	14 O

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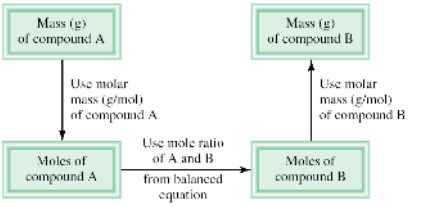
Amounts of Reactants and Products



1. Write balanced chemical equation
2. Convert quantities of known substances into moles
3. Use coefficients in balanced equation to calculate the number of moles of the sought quantity
4. Convert moles of sought quantity into desired units

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Methanol burns in air according to the equation

$2CH_3OH + 3O_2 \longrightarrow 2CO_2 + 4H_2O$

If 209 g of methanol are used up in the combustion, what mass of water is produced?

grams CH_3OH ⟶ moles CH_3OH ⟶ moles H_2O ⟶ grams H_2O

molar mass CH_3OH — coefficients chemical equation — molar mass H_2O

$$209 \text{ g } CH_3OH \times \frac{1 \text{ mol } CH_3OH}{32.0 \text{ g } CH_3OH} \times \frac{4 \text{ mol } H_2O}{2 \text{ mol } CH_3OH} \times \frac{18.0 \text{ g } H_2O}{1 \text{ mol } H_2O} =$$

235 g H_2O

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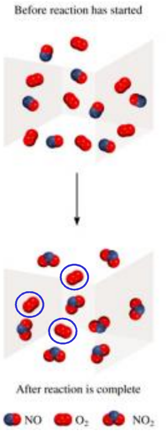
Limiting Reagent:

Reactant used up first in the reaction.

$2NO + O_2 \longrightarrow 2NO_2$

NO is the limiting reagent

O_2 is the excess reagent



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In one process, 124 g of Al are reacted with 601 g of Fe_2O_3

$2Al + Fe_2O_3 \longrightarrow Al_2O_3 + 2Fe$

Calculate the mass of Al_2O_3 formed.

g Al ⟶ mol Al ⟶ mol Fe_2O_3 needed ⟶ g Fe_2O_3 needed

OR

g Fe_2O_3 ⟶ mol Fe_2O_3 ⟶ mol Al needed ⟶ g Al needed

$$124 \text{ g Al} \times \frac{1 \text{ mol Al}}{27.0 \text{ g Al}} \times \frac{1 \text{ mol } Fe_2O_3}{2 \text{ mol Al}} \times \frac{160. \text{ g } Fe_2O_3}{1 \text{ mol } Fe_2O_3} = 367 \text{ g } Fe_2O_3$$

Start with 124 g Al ⟶ need 367 g Fe_2O_3

Have more Fe_2O_3 (601 g) so Al is limiting reagent

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Use limiting reagent (Al) to calculate amount of product that can be formed.

g Al ⟶ mol Al ⟶ mol Al_2O_3 ⟶ g Al_2O_3

$2Al + Fe_2O_3 \longrightarrow Al_2O_3 + 2Fe$

$$124 \text{ g Al} \times \frac{1 \text{ mol Al}}{27.0 \text{ g Al}} \times \frac{1 \text{ mol } Al_2O_3}{2 \text{ mol Al}} \times \frac{102. \text{ g } Al_2O_3}{1 \text{ mol } Al_2O_3} = 234 \text{ g } Al_2O_3$$

At this point, all the Al is consumed and Fe_2O_3 remains in excess.

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Reaction Yield

Theoretical Yield is the amount of product that would result if all the limiting reagent reacted.

Actual Yield is the amount of product actually obtained from a reaction.

$$\textbf{\% Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$

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Chemistry In Action: Chemical Fertilizers

Plants need: N, P, K, Ca, S, & Mg

$3H_2\ (g) + N_2\ (g) \longrightarrow 2NH_3\ (g)$

$NH_3\ (aq) + HNO_3\ (aq) \longrightarrow NH_4NO_3\ (aq)$

fluorapatite

$2Ca_5(PO_4)_3F\ (s) + 7H_2SO_4\ (aq) \longrightarrow$

$3Ca(H_2PO_4)_2\ (aq) + 7CaSO_4\ (aq) + 2HF\ (g)$

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