Week 1 Revision

Atom	Massive nucleus surrounded by cloud of very light electrons
Atomic number	***Z;*** number of protons in the nucleus of an atom. If number of protons = number of electrons then the atom is electrically neutral
Mass number	***A***; the total number of protons and neutrons in the nucleus of an atom

What are the numbers of protons, neutrons and electrons in:

$^{35}_{17}Cl$ $\quad$ $^{56}_{26}Fe^{2+}$

Relative atomic mass (A_r)

a.k.a. atomic weight or average atomic mass.

The average of the atomic masses of all the chemical element's isotopes as found in a particular environment, weighted by isotopic abundance.

Calculate the relative atomic mass of chlorine given that it consists of two isotopes:

$^{35}_{17}Cl$ 75.91% $\quad$ $^{37}_{17}Cl$ 24.09%.

$$A_r = \frac{34.97\times 75.91}{100} + \frac{36.98\times 24.09}{100}$$

$= 26.55 + 8.89$

$= 35.44$

Percentage composition

The percentage composition is the proportion of individual elements to molecular mass.

Calculate the percentage composition of Mg in MgO:

$$= \frac{A_r(\text{Mg})}{A_r(\text{MgO})}\times 100$$

$$= \frac{24.3}{(24.3+16)}\times 100$$

= 60.3%

Molecular and Empirical formulae

Defined as the simplest whole number ratio of atoms of different elements in the compound.

e.g. Glucose

Molecular formula is $C_6H_{12}O_6$

Empirical formula is CH_2O

To calculate an empirical formula:

1. List the constituent elements as a ratio
2. Obtain the corresponding % abundance (or mass)
3. Divide (2) above by the atomic weight (relative atomic mass)
4. Divide all values in (3) by the smallest value in (3)

Calculate the empirical formula of an oxide of lead which contains 86.6% lead

$$\text{Pb} : \text{O}$$
$$= \frac{86.6}{207.2} : \frac{13.4}{16.0}$$
$$= 0.418 : 0.838$$
$$= \frac{0.418}{0.418} : \frac{0.838}{0.418}$$
$$= 1 : 2$$

Thus, the empirical formula is PbO2

The empirical formula of certain carbohydrate is CH2O. If the relative molecular mass of the compound is 180, what is its molecular formula?

M_r (CH2O) = [12 + (2X1) +16]
= 30

M_r (compound) = 180

$$\frac{M_r(\text{compound})}{M_r(\text{CH2O})} = \frac{180}{30} = 6$$

Thus, the molecular formula is 6(CH2O)

= $C_6H_{12}O_6$

The Mole

It is the amount of substance which contains as many constituent entities as there are atoms in 12 g of ${}^{12}_{6}C$ isotope.
A mole of any substance consists of Avogadro's Number (N_a) *of* the constituent entities of that substance.
Entities are typically molecules but may also be atoms, ions, or atomic particles.

Formulae for number of moles (n)

For mass $n = \frac{m}{M}$ where m = mass in gram; M = molar mass

For solutions $n = CV$ where C = concentration in molar (mol/L) units; V = volume in L

For gases $n = \frac{pV}{RT}$ where P = pressure in KPa; V = volume in litres; R = gas constant = 8.31; T = temperature in ºK

For number of molecules $n = \frac{N}{Na}$ where N = the number of molecules; N_a = Avagadro's Number = 6.023 X 10^{23}

Calculate the number of moles (n) in:

1. 36 g of H_2O
   $n(H_2O)$ = m/M = 36 / 18 = 2 mol
2. 84.0 g of nitrogen gas
   $n(N_2)$ = m/M = 84.0 / 28.0 = 3.00 mol
3. 2 L of 0.1 M NaCl
   $n(O_2)$ = CV = 0.1 X 2 = 0.2 mol
4. 25 L of oxygen gas at 20ºC and 100kpa pressure
   $n(O_2)$ = pV/RT = (100 X 25) / [8.31 X (273+20)] = 1.027 mol
5. 4.1 X 10^{24} molecules of methane (CH_4)
   $n(CH_4)$ = N/N_a = (4.1 X 10^{24}) / 6.023 X 10^{23}) = 6.81 mol

Electrovalencies and Chemical Formulae

Chemical formulae must ensure that the overall positive charge of the cation balances that of the anion.

Write balanced chemical formulae for the following ionic substances:

1. Magnesium chloride
   $Mg^{2+} + 2Cl^{-} = MgCl_2$
2. Iron (II) sulphate
   $Fe^{2+} + SO_4^{2-} = FeSO_4$
3. Ammonium carbonate
   $2NH_4^{+} + CO_3^{2-} = (NH_4)_2CO_3$
4. Potassium dichromate
   $2K^{+} + Cr_2O_7^{2-} = K_2Cr_2O_7$
5. Copper (II) nitrate
   $Cu^{2+} + 2NO_3^{-} = Cu(NO_3)_2$

Writing chemical equations

Full molecular equations for reactions

The steps involved are:

1. Write a word equation.
2. Write chemical formulae for every species and show the physical state *viz.*
   solid = (s); gas = (g); liquid = (l); aqueous solution = (aq)
3. Put numbers in front of each formulae so that the number of atoms of each element is the same on the left hand side as the right hand side.

Write balanced molecular equations for the following:

1. Hydrogen gas reacts with oxygen to form water

   Word eqn.: hydrogen gas + oxygen gas → liquid water

   Chemical formula: H_2 (g) + O_2 (g) → H_2O (l)

   Balanced equation: $2H_2$ (g) + O_2 (g) → $2H_2O$ (l)

2. Silver nitrate solution reacts with sodium chloride solution to form a precipitate of silver chloride and a solution of sodium nitrate

   Word eqn.: Silver nitrate solution + sodium chloride solution → solid silver chloride + sodium nitrate solution

   Chemical formula: $AgNO_3$ (aq) + NaCl (aq) → AgCl (s) + $NaNO_3$ (aq)

   Balanced equation: $AgNO_3$ (aq) + NaCl (aq) → AgCl (s) + $NaNO_3$ (aq)

3. Sodium carbonate solution reacts with dilute hydrochloric acid to form sodium chloride solution and water and carbon gas

   Word eqn.: sodium carbonate + hydrochloric acid → sodium chloride + water + carbon gas

   Chemical formula: $NaCO_3$ (s) + HCl (aq) → NaCl (aq) + H_2O (l) + CO_2 (g)

   Balanced equation: Na_2CO_3 (aq) + 2HCl (aq) → 2NaCl (aq) + H_2O (l) + CO_2 (g)

Ionic equations

These show the particles that were involved in the reaction and omit the spectator ions which have not reacted.

The steps involved are:

1. Write a balanced molecular equation.
2. Rewrite the equation listing all the aqueous species as separate ions.
3. Write the ionic equation after cancelling out the common or spectator ions.

Write ionic equations for the following:

1. Silver nitrate solution + sodium chloride solution → solid silver chloride + sodium nitrate solution

Balanced equation:
$AgNO_3$ (aq) + NaCl (aq) → AgCl (s) + $NaNO_3$ (aq)

Ag^+ (aq) + NO_3^- (aq) + Na^+ (aq) + Cl^- (aq) → AgCl (s) + Na^+ (aq) + NO_3 (aq)

Ionic equation is:
Ag^+ (aq) + Cl^- (aq) → AgCl (s)

2. sodium carbonate + hydrochloric acid → sodium chloride + water + carbon gas

Balanced equation:
$2Na_2CO_3$ (aq) + 2HCl (aq) → 2NaCl (aq) + H_2O (l) + CO_2 (g)

2Na+ (aq) + CO_3^- (aq) + $2H^+$ (aq) + $2Cl^-$ (aq) → 2Na+ (s) + $2Cl^-$ (aq) + H_2O (l) + CO_2 (g)

Ionic equation is:
CO_3 (aq) + $2H^+$ (aq) → H_2O (l) + CO_2 (g)

Stoichiometry

Involves calculating amounts of products and reactants using chemical equations

The steps involved are:

1. Write a balanced chemical equation for the reaction.
2. List all given data, including relevant units.
3. Convert the data given into moles using the relevant formula *e.g.* n=m/M; n = CV *etc*.
4. Use the chemical equation to determine the mole ratio of the unknown quantity to the known quantity. This ratio enables calculation of the number of moles of the unknown quantity to be determined.
5. Finally, convert this number of moles back into the relevant units.

Example of mass – mass stoichiometry

A sample of 5.6 grams of sodium reacts with water to produce sodium hydroxide solution and hydrogen gas. Calculate the mass of hydrogen gas that forms.

$2Na\ (s) + 2H_2O\ (l) \rightarrow 2NaOH\ (aq) + H_2\ (g)$

Mass of sodium = 5.6 g

n(Na) = m/M = 5.6/23.) = 0.243 mol

Since 2 moles of Na gives 1 mole of H_2

Then, n(H_2) = ½ X 0.243 = 0.122 mol

Mass of H_2 = n(M) = 0.122 X 2 = 0.244 g

Calculations involving excess reactants

More complicated if reactants are not present in their stoichiometric ratio.

Determine which reactant is completely consumed (called the limiting reactant) and which on is present in excess.

The limiting reactant determines how much product is formed.

A solution containing 1.5 g of $AgNO_3$ reacts with 40 mL of 0.20 M Magnesium chloride solution. What mass of silver chloride is precipitated?

Step	Calculation
Write a balanced equation	$2AgNO_3\ (aq) + MgCl_2\ (aq) \rightarrow 2AgCl\ (s) + Mg(NO_3)_2\ (aq)$
Write the information under the relevant chemicals in the equation. Calculate the mol quantities of the chemicals for which the data is given.	m = 1.5 g, M = 170 g mol^{-1}, $n = \frac{1.5}{170}$ = 0.080 mol; V = 40 mL = 0.040 L, c = 0.20 M, n = 0.040 X 0.20 = 0.0080 mol
Determine if any reactant is in excess: Divide the moles of each reactant by its coefficient in the equation. The smallest of these answers is the limiting reactant. The moles of the limiting reactant is used to calculate the amount of product formed.	$\frac{n(AgNO_3)}{\text{coeff. of } AgNO_3} = \frac{0.0088}{2} = 0.0044$; $\frac{n(MgCl_2)}{\text{coeff. of } MgCl_2} = \frac{0.0080}{1} = 0.0080$; So $AgNO_3$ is the limiting reactant
Use the equation to calculate the amount, in mol, of the required substance: $\frac{n(\text{unkown reagent})}{n(\text{limiting reagent})} = \frac{\text{coeff. of the unknown reagent.}}{\text{coeff. of the limiting reagent}}$	$\frac{n(AgCl)}{n(AgNO3)} = \frac{2}{2}$; So n(AgCl) = n($AgNO_3$) = 0.0088 mol
Convert the amount, in mol, of the required substance into the appropriate quantity.	So m(AgCl) = 0.0088 X 143.4; m(AgCl) = 1.3 g

Calculate the mass of silver bromide formed:
15.0 g of silver nitrate (aq) + 10.0 g of calcium bromide (aq)

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$2AgNO_3\ (aq) + CaBr_2\ (aq) \rightarrow 2AgBr\ (s) + Ca(NO_3)_2\ (aq)$

Calculate mole quantities:

$$n(AgNO_3) = \frac{m(AgNO_3)}{M(AgNO_3)} = \frac{15.0}{169.9} = 0.0883 \text{ mol}$$

$$n(CaBr_2) = \frac{m(CaBr_2)}{M(CaBr_2)} = \frac{10.0}{199.9} = 0.0500 \text{ mol}$$

The balanced equation shows that:
2 mol $AgNO_3$ reacts with 1 mol $CaBr_2$
How many moles of $CaBr_2$ will be reacted?
0.0883 $AgNO_3$: ½(0.0883) $CaBr_2$
all the $AgNO_3$ will be consumed.
$AgNO_3$ is the limiting reactant; $CaBr_2$ is in excess

To calculate the amount of silver bromide formed:

$$\frac{n(\mathrm{AgBr})}{n(\mathrm{AgNO_3})} = \frac{1}{1}$$

$n(\mathrm{AgBr}) = n(\mathrm{AgNO_3})$
= 0.0883 mol

$m(\mathrm{AgBr}) = n(\mathrm{AgBr}) \text{ x } M(\mathrm{AgBr})$
= 0.0883 X 187.8
= 16.6 g

Magnesium reacts with hydrochloric acid according to the equation:

$Mg (s) + 2HCl (aq) \rightarrow MgCl (aq) + H_2 (g)$

If 10.0 g of magnesium reacts completely, calculate:

a. The mass of magnesium chloride that forms.

10 g Mg = 10/24.312 = 0.411 mol

$$\frac{n(\mathrm{Mg})}{n(\mathrm{MgCl})} = \frac{1}{1}$$

$n(\mathrm{Mg}) = n(\mathrm{MgCl})$
= 0.411 mol

$m(\mathrm{MgCl}) = n(\mathrm{MgCl}) \text{ x } M(\mathrm{MgCl})$
= 0.411 X 59.765
= 24.56 g

b. The mass of hydrogen that forms.

10 g mol Mg = 10/24.312 = 0.411 mol

$$\frac{n(\mathrm{Mg})}{n(\mathrm{H})} = \frac{1}{1}$$

$n(\mathrm{Mg}) = n(\mathrm{H})$
= 0.411 mol

$m(\mathrm{MgCl}) = n(\mathrm{MgCl}) \text{ x } M(\mathrm{H_2})$
= 0.411 X 2
= 0.822 g