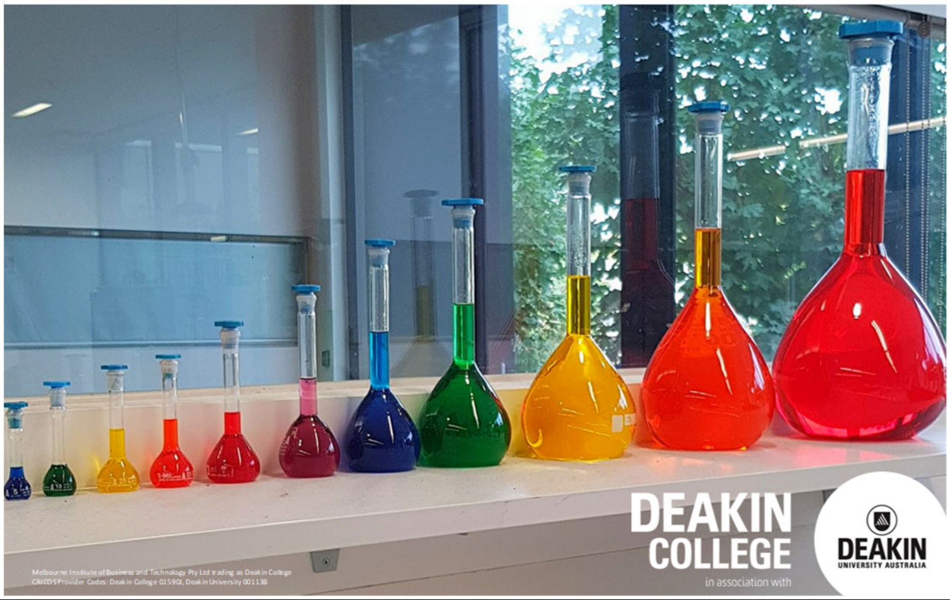
SLE155 Chemistry for the Professional Sciences

Burwood and Geelong



Class 1

Chapter 4: Chemical Reactions and Stoichiometry

Week 1 – revision of chemical structures, chemical reactions and stoichiometric calculations

Week 1

We will be covering all of chapter 4 of Chemistry Core Concepts

- 4.1 Chemical and Physical Changes
- 4.2 Chemical equations
- 4.3 Balancing Chemical equations
- 4.4 The mole
- 4.5 Empirical formula
- 4.6 Stoichiometry, limiting reagents, percentage yield
- 4.7 Solution stoichiometry

Learning Objectives

Understand stoichiometry

Use stoichiometry rules to determine

- Limiting reagents
- % yield

Extra worked out problems

Chemical and Physical change

- **Physical Change**—A change that does not affect the chemical makeup of a substance or object.
- **Chemical Change**—A change in the chemical makeup of a substance.

Burning potassium in water

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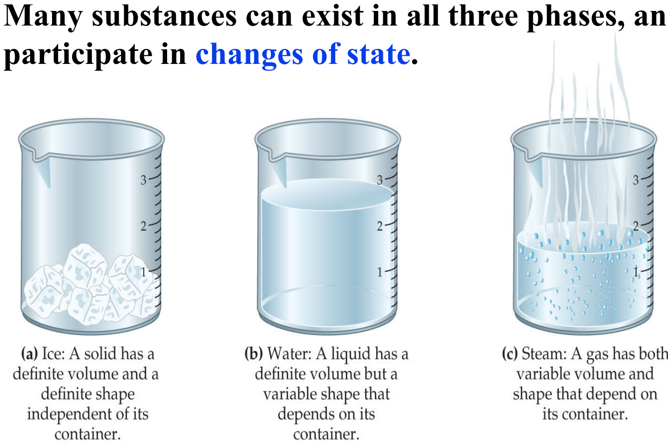
Physical Change

Many substances can exist in all three phases, and participate in changes of state.



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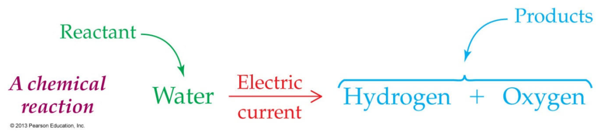
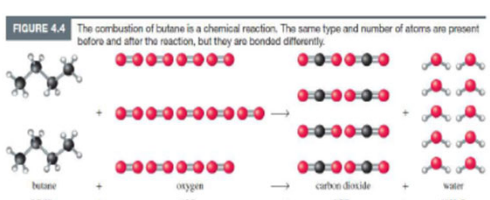
Chemical Change



Water can be chemically changed by passing an electric current through it to produce hydrogen and oxygen.

Chemical Change

- Same type and number of atoms present before and after a reaction.
- But bonded differently.



Chemical Change

- Oxidise: steel (Fe) to rust (Fe_2O_3).
- Acid-base: sodium bicarbonate ($NaHCO_3$) and lemon juice (citric acid $C_6H_8O_7$).
- Exothermic: releasing heat e.g. heat pack.
- Precipitation of sodium acetate crystals.
- Opposite is dissociation.
- Endothermic: absorbing heat e.g. light absorption.
- Chemiluminescence: generates light e.g. glow sticks.

Chemical Equations

$$\underbrace{2\,NaHCO_3}_{\text{Reactant}} \xrightarrow{\text{Heat}} \underbrace{Na_2CO_3 + H_2O + CO_2}_{\text{Products}}$$

A reactant is a substance that undergoes change in a chemical reaction and is written on the left side of the reaction arrow in a chemical equation.

A product is a substance that is formed in a chemical reaction and is written on the right side of the reaction arrow in a chemical equation. Necessary conditions are often (but not always) written above (and sometimes below) the arrow.

Chemical Equations

A coefficient is a number placed in front (to the left) of a formula to balance a chemical equation.

Coefficients multiply all of the atoms in the formula.

Be sure to always consider coefficients.

Substances that take part in chemical reactions may be solids, liquids, gases, or dissolved. This information is added to an equation by placing symbols after the formulas.

(*s*) = solid

(*l*) = liquid

(*g*) = gas

(*aq*) = aqueous solution (dissolved in water)

Balancing Chemical Equations

STEP 1: Write an unbalanced equation, using the correct formulas for all reactants and products.

For example, hydrogen and oxygen must be written as H_2 and O_2 rather than as H and O, since both elements exist as diatomic molecules.

Subscripts in chemical formulas cannot be changed because doing this would change the identity of the substances in the reaction.

Balancing Chemical Equations

STEP 2: Add appropriate coefficients to balance the numbers of atoms of each element.

Begin with elements that appear in only one compound or formula on each side of the equation.

Leave elements that exist in elemental forms, such as oxygen and hydrogen, until last.

$$H_2SO_4 + NaOH \longrightarrow Na_2SO_4 + H_2O \quad \text{(Unbalanced)}$$

$$H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + H_2O \quad \text{(Balanced for Na)}$$

Add this coefficient . . . . . . to balance these 2 Na.

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Balancing Chemical Equations

If a polyatomic ion appears on both sides of an equation, it is treated as a single unit.

Learn to recognise cations and anions!

$$H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + H_2O \quad \text{(Balanced for Na and sulfate)}$$

One sulfate here . . . . . . and one here.

$$H_2SO_4 + 2\,NaOH \longrightarrow Na_2SO_4 + 2\,H_2O \quad \text{(Completely balanced)}$$

4 H and 2 O here. 4 H and 2 O here.

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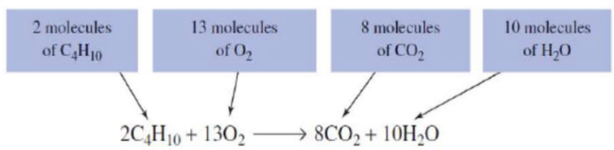
Balancing Chemical Equations

- Stoichiometry is concerned with the relative amounts of reactants and products in a chemical reaction. Stoichiometric coefficients are used to balance an equation to meet this condition



Balance the equation

$$K_2Cr_2O_7 + BaCl_2 + H_2O \rightarrow BaCrO_4 + KCl + HCl$$

The Mole and Avogadro's Number

Atomic mass is the average mass of an element's *atoms*.

Molecular mass is the average mass of a substance's *molecules*.

A substance's molecular mass (or formula mass for an ionic compound) is the sum of the atomic masses for all the atoms in the molecule (or formula unit for ionic compounds).

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The Mole and Avogadro's Number

A mole is the amount of a substance whose mass in grams is numerically equal to its molecular or formula mass.

One mole of any substance contains 6.022×10^{23} formula units.

This value is called Avogadro's number (abbreviated N_A) after the Italian scientist who first recognised the importance of the mass/number relationship in molecules.

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Gram-Mole Conversions

Molar mass (M_r) is the mass, in grams, of 1 mol of a substance, numerically equal to molecular mass or formula mass.

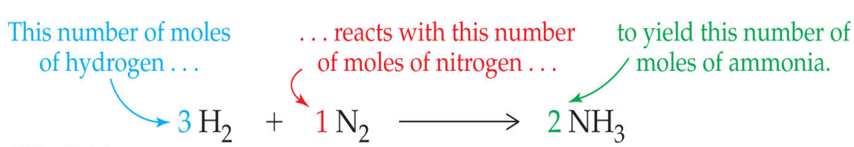
Unit is g/mol or g mol^{-1}

Molar mass serves as a conversion factor between amount in moles and mass.

Mole Relationships and Chemical Equations

In chemical reactions, the unit to specify the relationship between reactants and products is the mole.

Coefficients in a chemical equation tell how many *molecules* or *formula units*, and thus how many *moles*, of each reactant are needed and of each product are formed.



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Mass Relationships and Chemical Equations

Coefficients in a balanced chemical equation represent **molecule-to-molecule** or **formula unit-to-formula unit** or **mole-to-mole** relationships between reactants and products.

Actual amounts of substances used in the laboratory are weighed out in grams.

Three types of conversions are needed when doing chemical arithmetic.

Mass Relationships and Chemical Equations

- **Mole to mole conversions are carried out using *mole ratios* as conversion factors.**

Use mole ratio as a conversion factor.

Moles of A (known) ⟶ Moles of B (unknown)

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Mass Relationships and Chemical Equations

Rusting involves the reaction of iron with oxygen to form iron(III) oxide.

$$4\ Fe\ (s) + 3\ O_2\ (g) \rightarrow 2\ Fe_2O_3\ (s)$$

(a) What are the mole ratios of the product to each reactant and of the reactants to each other?

(b) What is the amount in moles of iron(III) oxide formed by the complete oxidation of 6.2 mol of iron?

Mass Relationships and Chemical Equations

- **Mole-to-mass and mass-to-mole conversions are carried out using *molar mass* as a conversion factor.**

Use molar mass as a conversion factor.

Moles of A $\longleftrightarrow$ Mass of A (in grams)

Mass Relationships and Chemical Equations

WORKED EXAMPLE
Molar Mass: Mole to Gram Conversion

The nonprescription pain relievers Advil and Nuprin contain ibuprofen, whose molecular mass is 206.3 u. If all the tablets in a bottle of pain reliever together contain 0.082 mol of ibuprofen, what is the number of grams of ibuprofen in the bottle?

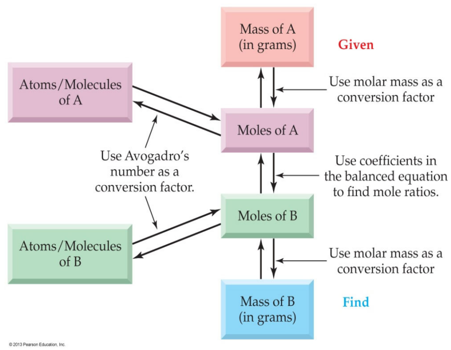
Mass Relationships and Chemical Equations

SOLUTION

STEP 1: **Identify known information.**	0.082 mol ibuprofen in bottle
STEP 2: **Identify answer and units.**	mass ibuprofen in bottle = ?? g
STEP 3: **Identify conversion factor.** We use the molecular weight of ibuprofen to convert from moles to grams.	1 mol ibuprofen = 206.3 g $\frac{206.3\text{ g ibuprofen}}{1\text{ mol ibuprofen}}$
STEP 4: **Solve.** Set up an equation using the known information and conversion factor so that unwanted units cancel.	$0.082\ \cancel{\text{mol } C_{13}H_{18}O_2} \times \frac{206.3\text{ g ibuprofen}}{\cancel{1\text{ mol ibuprofen}}} = 17\text{ g } C_{13}H_{18}O_2$

Mass Relationships and Chemical Equations

- **Mass to mass conversions** cannot be carried out directly. If you know the mass of A and need to find the mass of B, first convert the mass of A into moles of A, then carry out a mole to mole conversion to find moles of B, then convert moles of B into the mass of B.



Empirical formulae

The empirical formula is the simplest whole-number ratio of atoms within that compound.

For example, butane has the molecular formula: C_4H_{10}

However this isn't the simplest ratio as both 4 and 10 are divisible by 2.

Hence butane has the empirical formula: C2H5

Empirical formulae

Percentage composition: the relative masses of elements in a compound can be given as a percentage.

The percentage by mass of an element calculation:

$$\% \text{ element} = \frac{\text{mass of element}}{\text{mass of whole sample}} \times 100$$

Empirical formulae

- **Step 1: Assume we are studying 100g of the compound. Individual mass percentages become the actual masses.**
- **Step 2: Divide the mass of each element by its molar mass.**
  This calculates the number moles of each element as a ratio.
- **Step 3: Divide all numbers in the ratio by the smallest number of moles.**
  This gives the smallest whole-number ratios of each element.

Empirical Formula

Magnetite is a binary compound containing only iron and oxygen. The percent, by weight, of iron is 72.360%. What is the empirical formula of magnetite?

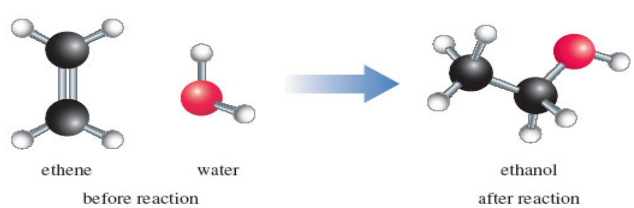
a. FeO
b. FeO_2
*c. Fe_3O_4
d. Fe_2O_3
e. Fe_2O_5

Limiting reagents

Ethanol, C_2H_5OH, can be prepared industrially

$$C_2H_4(g) + H_2O(l) \rightarrow C_2H_5OH(l)$$

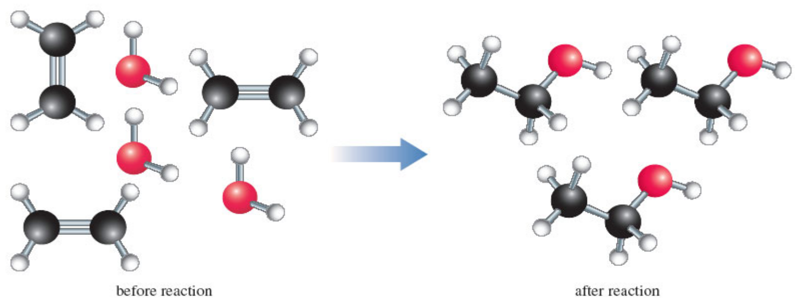
The chemical equation says that 1 molecule of ethene will react with 1 molecule of water to give 1 molecule of ethanol



Limiting reagents

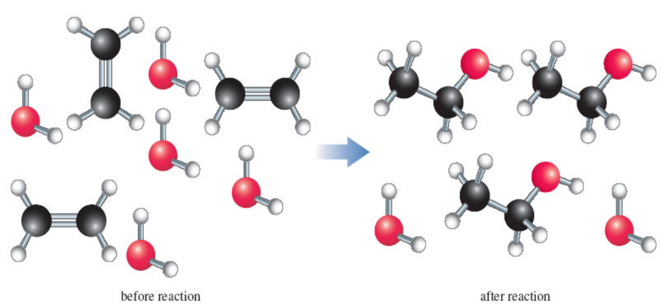
The mole-to-mole ratio is constant.

3 molecules of ethene will react with 3 molecules of water to give 3 molecules of ethanol.



Limiting reagents

If we mix 3 molecules of ethene with 5 molecules of water,



the ethene will be completely used up, and the product will contain 2 unreacted water molecules.

Calculate theoretical Yield

PI_3 (M = 411.69 g mol-1) and water (M = 18.015 g mol-1) react to form H_3PO_3 (M = 81.996 g mol-1) and HI(M = 127.91 g mol-1). If 0.5000 moles of phosphorus triiodide and 2.500 moles of water are used, what is the theoretical yield of hydrogen iodide?

a. 63.96 g

b. 205.8 g

*c. 191.9 g

d. 319.8 g

e. 383.7 g

Percentage yield

In most experiments, the amount of a product isolated is less than the maximum amount.

- **The actual yield of the desired product is simply how much is isolated.**
- **The theoretical yield of the product is what would be obtained if no losses occurred.**
- **The percentage yield is the actual yield calculated as a percentage of the theoretical yield.**

Percentage yield

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

The calculation may be done in either grams or moles, but both yields must be in the same units.

The actual yield can never be more than the theoretical yield.

Percentage yield

The combustion of acetylene gas (C_2H_2) produces carbon dioxide and water as indicated in the following reaction.

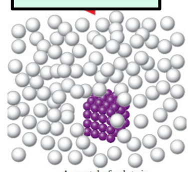
$$2\ C_2H_2\ (g) + 5\ O_2\ (g) \rightarrow 4\ CO_2\ (g) + 2\ H_2O\ (g)$$

When 26.0 g of acetylene is burned in sufficient oxygen for complete reaction, the theoretical yield of CO_2 is 88.0 g. Calculate the percent yield for this reaction if the actual yield is only 72.4 g CO_2.

Solution stoichiometry

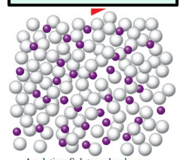
SOLUTION
homogeneous mixture

SOLUTE



A crystal of solute is placed in the solvent.

SOLVENT



A solution. Solute molecules are dispersed throughout the solvent.

solvent molecule (ethanol)

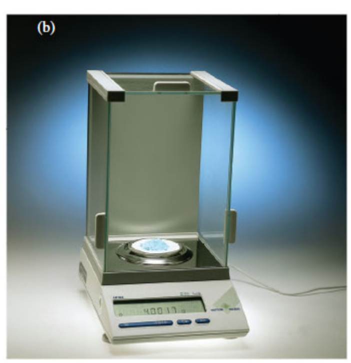
solute molecule (iodine)

Solution stoichiometry

$$c = \frac{n}{V}$$

$$M_r = \frac{m}{n}$$

Typical 'tools of the trade' for chemists



Solution stoichiometry

Solution concentration [X] is the ratio of the amount of solute to the volume of solution

The units of c are mol L^{-1}

$$c = \frac{n}{V}$$

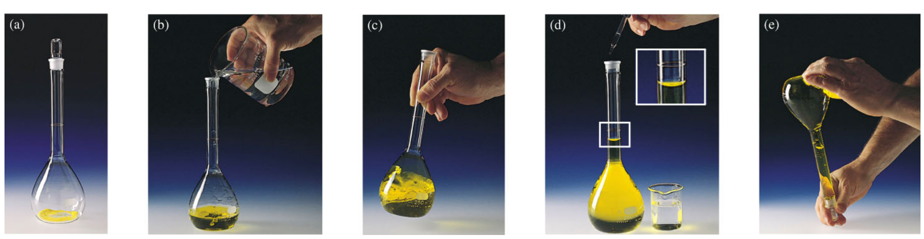
n is the number of moles (recall $M_r = m/n$)

V is the volume (in litres)

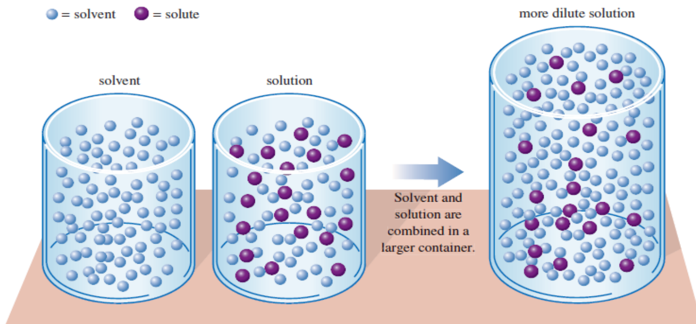
Molarity (or molar concentration) has the units mol L^{-1} (abbreviated M)

Solution stoichiometry

A standard solution is one whose concentration is accurately known.



Solution stoichiometry



When solvent is added to a solution, the solute particles become more spread out so the concentration of the solute in the solution is less.

This process is called dilution.

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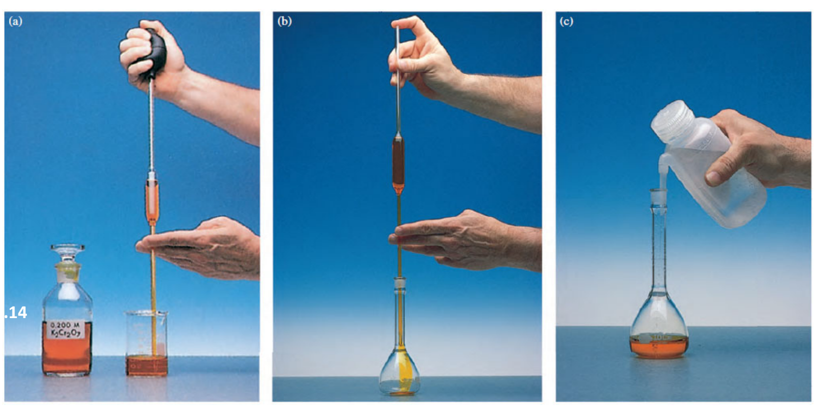
Diluting a solution



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Solution stoichiometry

Ionic compounds dissociate into their constituent ions when dissolved in water.

This can have important consequences in stoichiometric calculations.

e.g., $CaBr_2$ undergoes complete dissociation into Ca^{2+} and Br^- ions, according to the equation

$CaBr_2(s) \rightarrow Ca^{2+}(aq) + 2Br^-(aq)$

0.10 moles of $CaBr_2$ yields 0.10 moles of Ca^{2+} and 0.20 moles of Br^-

In 0.10 M $CaBr_2$, the concentration with respect to Ca^{2+} is 0.10 M

but the concentration with respect to Br^- is 0.20 M

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Solution stoichiometry

Spectator ions do not take part in reactions.

Balanced ionic equations are written without including the spectator ions

These are called net ionic equations,e.g.,

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

The NO_3^- and Ca^{2+} ions do not take part in the reaction

Q. What is the net ionic equation?

A. $Ag^+(aq) + Br^-(aq) \rightarrow AgBr(s)$

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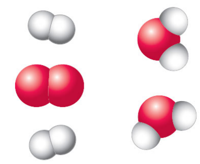
Summary of Chapter 4

A chemical reaction is the formation of new substances (products) when two or more chemical species (reactants) are mixed.



$2H_2 + O_2 \longrightarrow 2H_2O$

Stoichiometry is concerned with relative amounts of products and reactants.

A balanced chemical equation has the same number of entities of each kind in the products and reactants and should show the physical states of the reactants and products.

Summary of Chapter 4

An empirical formula gives the smallest whole-number ratio of atoms.

% composition is used to describe the relative amount of each element in a compound.

A reactant present in the smallest quantity is called the limiting reagent. The other reactant is called the excess reagent.

$$\boxed{c = \frac{n}{V}} \qquad \boxed{M_r = \frac{m}{n}}$$

Summary of Chapter 4

The **percentage yield** is the actual yield calculated as a percentage of the theoretical yield.

When a **solution** forms, at least two substances are involved, the **solute** and the **solvent**.

Concentration is the ratio of the amount of solute to the volume of solution.

Ionic compounds dissociate into their constituent ions when dissolved in water.

Spectator ions do not take part in reactions.