Topic 1: Quantitative Chemistry

▼ 1.1 Introduction to the particulate nature of matter and chemical change

Definitions

Matter: Anything that takes up space (can refer to particles or mixtures)

Pure Substance: Particles will all look the same with constant composition

Element: Atoms all having the same number of protons

Molecule: Two or more elements chemically joined together

Compounds: Two or more different elements chemically joined together in a fixed ratio

Mixture: A combination of pure substances (not chemically bonded)

Homogeneous vs Heterogeneous Mixtures

- Both contain more than one element/compound that are not chemically bonded
- Homogeneous mixtures will be the same mixture throughout, having a uniform composition
- Heterogeneous mixtures will have a different mixture throughout, visually shown to be non-uniform and different in different parts of the mixture

Chemical Equation

- A Chemical Equation describes what happens in a chemical reaction with reactants and products

- They are shown like this: Reactants → Products
- Chemical equations usually include state symbols

State Symbols

- (s): solid
- (l): Liquid
- (g): gas
- (aq): aqueous soution

Physical and Chemical Changes

- In a physical change, there is no altering of chemical composition in the substances (no products are formed)
- Examples of physical change include change in state
- In a chemical change, there is a change in chemical composition, in which the atoms in the reactants are rearranged to form new products.

▼ 1.2 The mole concept and Avogadro's constant

The Mole

- A mole is a unit of the amount of substance that contains the same number of specifed particles as there are atoms in 12g of Carbon-12
- The mole is used to quantify the amount of particles present in grams. These are really large numbers, and are therefore expressed in moles.
- A mole is given by the symbol n
- The number of particles in 1 mole is defined by the Avogadro's constant, which is **6.02×10^{23} particles**
- The formula to find the number of particles is the folliwing

📜 Number of Particles = Number of Moles x Avogadro's constant

📜 Example:

To calculate the number of O_2 molecules in 1.5 mole of oxygen will be calculated as following

$N = 6.02 \times 10^{23}$ (Avogardo's constant) x 1.5(mol)

$N = 9 \times 10^{23}$

Mole Relationships

- Moles of individual atoms that make up a moles of a molecule

📜 Example:
1 mol of C + 4 mol of H → 1 mol of CH_4

- To find the number of mols in an element, you can use the following formula

📜 Number of mols in an element = Number of mols of molecule x Number of elements within molecule

Mole Concept

- One mole also weighs the element/compounds's mass number in grams (eg. 1 mol of oxygen is 15.999 grams, 1 atom of oxygen has a mass number of 15.999)
- In other words, the mass number of an element is equal to the relative molecular mass (molar mass) to an element as well
- The relative molecular mass (aka molar mass) has a unit of g mol^{-1}

Amount of moles

- To calculate the number of moles, this is the formula

> Moles = Mass ÷ Molar Mass

> Example:
> To calculate the amount of mol in 32g of O_2, we would do the following working
>
> Since the molar mass of O_2 is 16, and total mass is 32g, the number of moles can be worked out by 32 ÷ 16
>
> Therefore, there are 2 moles in 32g of O_2

Percentage Composition

- The values of molar masses of elements within compounds can be used to calculate percentage composition of a compound
- This can be worked out by the following equation

> Percentage Composition by Mass of Element = Molar Mass of the Element/ Molar Mass of the Compound

Empirical Formula

- The empirical formula is the formula of a compound that shows the lowest whole number ratio of each type of atom
- This can be calculated through the following equation

📜 Percentage Composition of Element/Mass : Percentage Composition of Element/Mass (to nearest whole number)

Molecular formula

- The molecular formula is a formula of a compound that shows the number of each type of atom in a molecule
- The molecular formula is always a whole multiple of the em[pirical formula

Atom economy

- The atom economy of a chemical reactionmesures the amount of starting materials that become useful product, which acts as sa mesaure of efficiency of a reaction
- Thus, a reaction with a higher atom economy has a better efficiency with less waste
- The formula for an atom economy is the following

📜 Atom Economy = Total Mass of Desired Products ÷ Total Mass of All Products or Reactants

▼ 1.3 Reacting masses and volumes

Limiting/Excess Reactants

- The limiting reactant is the reactant that will be used up first in a chemical reaction
- The excess reactant is the reactant that will be left over after the reaction ends (when limiting reactant is used up)

- To find out which is the limiting reactant, divide the number of moles by the leading coefficient
- The reactant with the lower result is the limiting reactant

> 📜 Example:
> Find the limiting reactant when 5 moles of S react with 18 moles of F_2 in the following reaction
>
> $S + 3F_2 \rightarrow SF_6$
>
> (For S): $5 \div 1 = 5$
> (For F_2): $18 \div 3 = 6$
>
> As the answer for S was smaller, sulfur is the limiting reactant

Percentage Yield

- The percentage yield of an experiment is the percent ratio between the actual and theoretical (predicted) yield in an experiment
- The actual experimental yield may differ from the theoretical yield due to a variety of factors such as
    - Measurement error
    - Some reactants may not react
    - Some of the reactants may form other products
- The formula to find percentage yield is the following

> 📜 Percentage yield (%) = Actual Yield ÷ Theoretical Yield x 100

Theory of an ideal gas

- The kinetic molecular theory of gases explains the behaviour of gases through the following properties
    - Particles are in continuous random motion in straight directions
    - Particles have perfect elastic collision (there is no net loss of kinetic energy from before and after collision)
    - The average kinetic energy of the particles are directly proportional to temperature
    - Volume of gas is negligible (so small they can be ignored)
    - Intermolecular forces are negligible (attraction is so small it can be ignored)
- Depsite this theory, in reality, no gas is perfectly ideal and adheres to all behaviours above

Ideal Gas Equation

- The ideal gas equation related different properties of gases as following
- With this equation, you can work out certain aspects (eg. pressure, temperature, etc.)

$$PV = nRT$$

P: Pressure (Pa)
V: Volume (m^3)
n: Number of moles
T: Temperature (K)
R: Universal gas constant (8.31)

Combined Gas Equation

- The combined gas law is an equation formed from the concepts that
    - Pressure is inversely proportional to volume at constant temperature
    - Volume is directly proportional to temperature (at constant pressure)
    - Pressure is directly proportional to temperature (at constant volume)
- The combined gas law is the following

📜 $(P_1V_1)/T_1 = (P_2V_2)/T_2$

Real vs Ideal Gases

- At high temperatures and low pressures, gases behave closest to an ideal gas
- An ideal gas has the following features
    - Particles are in continuous random motion in straight directions
    - Particles have perfect elastic collision (there is no net loss of kinetic energy from before and after collision)
    - The average kinetic energy of the particles are directly proportional to temperature
    - Volume of gas is negligible (so small they can be ignored)
    - Intermolecular forces are negligible (attraction is so small it can be ignored)

Comparison Chart (Real Gases vs. Ideal Gases)

Real Gases	Ideal Gases
Gas particles have volume	Particle volume negligible
Intermolecular forces present	Intermolecular forces negligible

Molar Volume

- Molar volume is the volume of one mole of gas at a certain temperature and pressure
- Avogrado's law states that 1 mol of any gas at standard temperature and pressure (273K and 100kPa), any gas will occupy 22.7dm^3
- The formula to determine the volume of a gas is the following

> 📜 Moles = Molar Volume ÷ Volume of Gas

Molar Concentrations

> 📜 Definitions
> Solute: The component in a solution that is dissolved
> Solvent: The component in a solution that the solute disolves in
> Solution: The homologous mixture of the solut eand solvent
> Concentration: A measure of solute (mol) per solution (dm^3)

- The following is the formula to calculate concentration

> 📜 Concentration = n/v
>
> n: mole of solute
> V: volume of solution

Addition of solutions

- To calculate the new concentration in a mixture of solutions, add the number of moles from each individual solution and substitute in the formula above to find the concentration of a solution

- Here are the steps to calculate the new concentration in added solutions

> 📜 Concentration of new solution = $((c_1 \times v_1) + (c_2 \times v_2))/(v_1 + v_2)$
>
> c_1: concentration of first solution
> v_1: volume of first solution
> c_2: concentration of second solution
> v_2: volume of second solution

Dilution

- Dilution is the process of adding more solvent to a solution
- By adding more solvent to a solution, solute particles will be more spaced out

Dilution formula

> 📜 $C_1V_1 = C_2V_2$