1.3 Reacting masses and volumes

Nature of science:

Making careful observations and obtaining evidence for scientific theories—Avogadro's initial hypothesis. (1.8)

Understandings:

- Reactants can be either limiting or excess.
- The experimental yield can be different from the theoretical yield.
- Avogadro's law enables the mole ratio of reacting gases to be determined from volumes of the gases.
- The molar volume of an ideal gas is a constant at specified temperature and pressure.
- The molar concentration of a solution is determined by the amount of solute and the volume of solution.
- A standard solution is one of known concentration.

Applications and skills:

- Solution of problems relating to reacting quantities, limiting and excess reactants, theoretical, experimental and percentage yields.
- Calculation of reacting volumes of gases using Avogadro's law.
- Solution of problems and analysis of graphs involving the relationship between temperature, pressure and volume for a fixed mass of an ideal gas.
- Solution of problems relating to the ideal gas equation.
- Explanation of the deviation of real gases from ideal behaviour at low temperature and high pressure.
- Obtaining and using experimental values to calculate the molar mass of a gas from the ideal gas equation.
- Solution of problems involving molar concentration, amount of solute and volume of solution.
- Use of the experimental method of titration to calculate the concentration of a solution by reference to a standard solution.

Guidance:

- Values for the molar volume of an ideal gas are given in the data booklet in section 2.
- The ideal gas equation, $PV = nRT$, and the value of the gas constant (*R*) are given in the data booklet in sections 1 and 2.
- Units of concentration to include: g dm^{-3}, mol dm^{-3} and parts per million (ppm).
- The use of square brackets to denote molar concentration is required.

International-mindedness:

- The SI unit of pressure is the Pascal (Pa), N m^{-2}, but many other units remain in common usage in different countries. These include atmosphere (atm), millimetres of mercury (mm Hg), Torr, bar and pounds per square inch (psi). The bar (10^5 Pa) is now widely used as a convenient unit, as it is very close to 1 atm. The SI unit for volume is m^3, although litre is a commonly used unit.

Theory of knowledge:

- Assigning numbers to the masses of the chemical elements has allowed chemistry to develop into a physical science. Why is mathematics so effective in describing the natural world?
- The ideal gas equation can be deduced from a small number of assumptions of ideal behaviour. What is the role of reason, perception, intuition and imagination in the development of scientific models?

Utilization:

- Gas volume changes during chemical reactions are responsible for the inflation of air bags in vehicles and are the basis of many other explosive reactions, such as the decomposition of TNT (trinitrotoluene).
- The concept of percentage yield is vital in monitoring the efficiency of industrial processes.

Syllabus and cross-curricular links:
Topic 4.4—intermolecular forces
Topic 5.1—calculations of molar enthalpy changes
Topic 9.1—redox titrations
Topic 17.1—equilibrium calculations
Topic 18.2—acid-base titrations
Topic 21.1 and A.8—X-ray crystallography
Physics topic 3.2—Ideal gas law

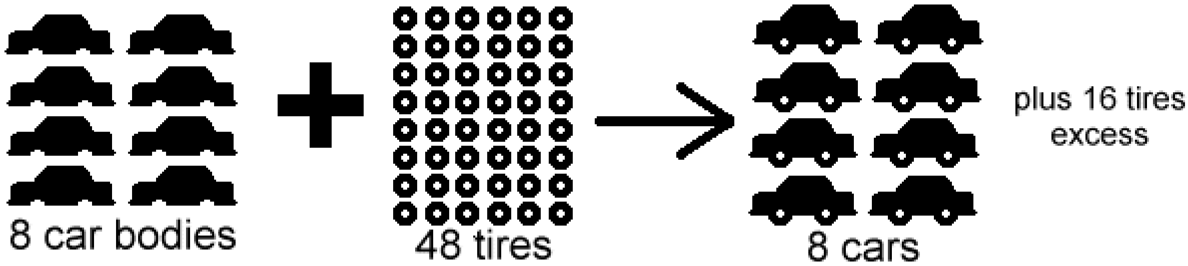
Aims:

- **Aim 6**: Experimental design could include excess and limiting reactants. Experiments could include gravimetric determination by precipitation of an insoluble salt.
- **Aim 7**: Data loggers can be used to measure temperature, pressure and volume changes in reactions or to determine the value of the gas constant, *R*.
- **Aim 8**: The unit parts per million, ppm, is commonly used in measuring small levels of pollutants in fluids. This unit is convenient for communicating very low concentrations, but is not a formal SI unit.

Stoichiometry: A method of examining the relative amounts of reactants and products. This will enable us to find the percentage yield.

THE LIMITING REAGENT

In an equation, the limiting reagent is the substance that limits the other, causing the other substance to have an excess.



The remaining reactants are present in amounts that exceed those required tro react with the limiting reagent. They are said to be **in excess**.

THEORETICAL YIELDS

In a reaction, many factors result in a reduced yield of products.

- Loss of products from reaction vessel
- Impurity of reactants
- Change in reaction conditions
- Reverse reactions consuming products in equilibrium systems
- The existence of side-reactions due to the presence of impurities

$$\%Yield = \frac{Experimental\ Yield}{Theoretical\ Yield} * 100$$

AVOGADRO'S LAW

Kinetic Theory of Gases: A model used to explain and predict the behaviour of gases at a microscopic level.

1. Gases are made up of very small particles, separated by large distances. Most of the volume occupied by a gas is empty space.
2. Gaseous particles are constantly moving in straight lines, but random directions.
3. Gaseous particles undergo elastic with each other and the walls of the container. No loss of kinetic energy occurs.
4. Gaseous particles exert no force of attraction on other gases.

Avogadro's Law states that equal volumes of all gases at the same temperature and pressure contain the same number of particles.

$$n = \frac{v}{molar\ volume}$$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

At STP (standard temperature (0^{o}C) pressure (100kPA) molar volume = 22.7 dm^3 mol^{-1}

GAS LAWS

$$\text{Boyle's law:} \quad V \propto \frac{1}{P} \quad (\text{constant } n,\ T)$$

$$\text{Charles's law:} \quad V \propto T \quad (\text{constant } n,\ P)$$

$$\text{Avogadro's law:} \quad V \propto n \quad (\text{constant } P, T)$$

COMBINED GAS LAW

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

THE IDEAL GAS EQUATION

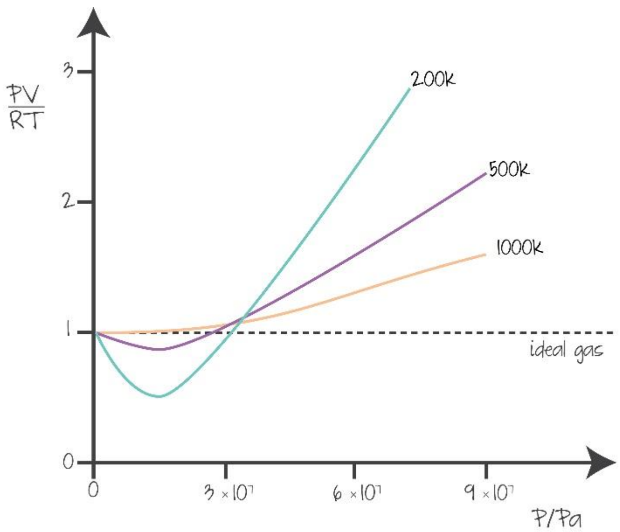
$$pV = nRT$$

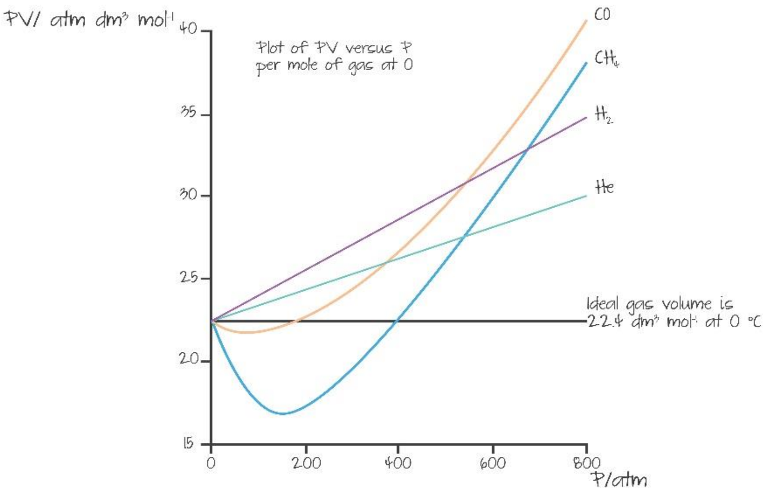
R = the **gas constant** which is 8.31 J K^{-1} mol^{-1}.

IDEAL GASES

A gas that obeys the ideal gas equation (and all the gas laws) under all conditions is said to be an **ideal gas** or a gas that behaves ideally.

- **Very high pressure:** The gas molecules are closer together and the volume becomes significant.
- **Low temperatures:** The particles move less rapidly. **Greater chance of interaction between them.**





CONCENTRATION

Solute: The substance to be dissolved

Solvent: The substance doing the dissolving

Molar concentration: The amount (in mol) of a substance dissolved in 1 dm^3 of solvent.

$$concentration = \frac{amount\ of\ substance\ (mol)}{volume\ of\ solution\ (dm^3)}$$

TITRATIONS

Pipette: Used to measure a known volume of one of the solution into a **conical flask**.

Burette: A calibrated glass tube that can deliver precise volumes into the conical flask through opening the tap at the bottom.