20 Gases

20.1 The Experimental Gas Laws

The **pressure** of a gas is the force per unit area that the gas exerts normally on a surface.

The unit of pressure is the **pascal**, $1\text{Pa} = 1\text{N}\,\text{m}^{-2}$.

The pressure of gas depends on

- Its **temperature**.
- The **volume** of the gas container.
- The **mass** of gas in the container.

Boyle's Law

Boyle's law states that for a **fixed mass** of gas at **constant temperature**.

$$pV = \text{constant}$$

For a constant temperature, the measurements plotted on a graph of **pressure against** $\mathbf{\dfrac{1}{volume}}$ is a straight line through the origin.

Any change at constant temperature is called an **isothermal change**.

Charles' Law

For a **fixed mass** of gas at **constant pressure**. Charles' law states the relation between volume and temperature in kelvins can be written as

$$\frac{V}{T} = \text{constant}$$

For a constant pressure, the measurements plotted on a graph of **volume against temperature** is a straight line through the origin - no matter how much gas is used, the volume of an ideal gas is zero at **absolute zero**.

Any change at constant pressure is called an **isobaric change**.

- When work is done to change the volume of gas, energy must be **transferred by heating** to keep the pressure constant.

$$\text{Work done} = p\Delta V$$

The Pressure Law

For a **fixed mass** of gas at **constant volume**, the pressure law states the relation between pressure and temperature can be written as

$$\frac{p}{T} = \text{constant}$$

20.2 The Ideal Gas Law

The molecules of a gas **move at random with different speeds**, when a molecule collides with another molecule or with a solid surface, it bounces off **without losing speed**.

The pressure of a gas on a surface is due to the gas molecules hitting the surface.

1. Each impact causes a tiny force on the surface.
2. Because there is a very large number of impacts each second.
3. The overall result is that the gas exerts a measurable pressure on the surface.

Smoke particles **wriggle about unpredictably**

1. Because it is **bombarded unevenly** and randomly by individual molecules.
2. The particle therefore experiences forces due to these impacts.
3. Which **change its magnitude and direction** at random.

This type of motion is called **Brownian motion**, it showed the existence of molecules and atoms.

Molar Mass

- The **Avogadro constant** N_A is defined as the number of atoms in exactly 12g of the carbon isotope ${}^{12}_{6}C$.
$$N_A = 6.02 \times 10^{23}$$
- One **atomic mass unit** u is $\frac{1}{12}$ of the mass of a ${}^{12}_{6}C$ atom.
$$1u = 1.66 \times 10^{-27}\text{kg}$$
- One **mole** of substance consists of identical particles is defined as the quantity of substance that contains N_A particles.
- The number of moles in a given quantity is its **molarity**.

  The unit of molarity is the **mol**.
- The **molar mass** of a substance is the mass of 1 mol of that substance.

  The unit of molar mass is $\text{kg}\,\text{mol}^{-1}$

$$\begin{aligned}\text{Number of moles } n &= \frac{\text{mass of substance } M_S}{\text{molar mass of substance } M} \\ \text{Number of molecules} &= nN_A\end{aligned}$$

The Ideal Gas Equation

An ideal gas is a gas that obeys Boyle's law.

The three experimental gas laws can be combined to give the equation

$$\frac{pV}{T} = \text{constant}$$

where T is the absolute temperature.

Equal volumes of ideal gases at the same temperature and pressure contains **equal number of moles**.

For 1 mol of any ideal gas, the value of $\frac{pV}{T} = 8.61\,\mathrm{J\,mol^{-1}K^{-1}}$, this value is called the **molar gas constant** R - the graph of pV against against T for n moles is a **straight line through absolute zero** and has a gradient equal to nR.

For n moles of ideal gas

$$pV = nRT$$

This equation is called the **ideal gas equation**.

The **Boltzmann constant** $k = \frac{R}{N_A} = 1.38 \times 10^{-23}\mathrm{JK^{-1}}$

$$\begin{aligned} pV &= nRT \\ &= \frac{N}{N_A}RT \\ &= N\frac{R}{N_A}T \\ &= NkT \end{aligned}$$

Density of Ideal Gas

Since the mass of a substance M_S = molar mass $M \times n$, and $n = \frac{pV}{RT}$.

$$M_S = M \times \frac{pV}{RT}$$

And the **density** of an ideal gas with molar mass M

$$\rho = \frac{M_S}{V} = \frac{pM}{RT}$$

Showing for an ideal gas at **constant pressure**

$$\rho \propto \frac{1}{T}$$