Learning Objectives

At the end of this unit you should be able to;

- Describe the three experimental gas laws in terms of particle behavior and use them to;
    - calculate pressure after a change in volume or temperature
    - calculate volume after a change in pressure or temperature
    - calculate temperature after a change in volume or pressure
- Describe what is meant by an isothermal change
- Define the mole as a measurement of quantity and link to the molar mass of a substance
- Define an Ideal gas
- Sate and preform calculations using the ideal gas equation
- Combine the experimental gas laws and use them to preform 'before and after' calculations to evaluate the pressure, volume or temperature of a system

Introduction.

Applications of the three experimental gas Laws (which describe how a gas behaves when pressure, volume or temperature of the gas is altered) are to numerous to list. For instance, hot gases in engines expanding to drive pistons, heat causing expansion and making a hot air balloon lighter than air, and a submarine being crushed if it exceeds its maximum dive depth are all examples of a gas behaving in accordance with the experimental gas laws. The gas laws also allowed the coldest possible temperature in the universe to be defined.

The formation of the experimental gas laws begin with Italian physicist Evangeliste Torricelli who in 1643, became the first person to measure atmospheric pressure (the force at sea level exerted per unit area by the weight of the air in the atmosphere). He took a 1m long glass tube, sealed at one end, and filled it with mercury (a heavy liquid metal at room temperature). When he inverted the tube and placed the open end into a mercury bath, the level of mercury in the tube dropped to 76cm. He concluded that the pressure of the atmosphere pushing down on the mercury bath balanced the weight of the 76cm of mercury in the tube.

These experiments sparked the interest of English physicist Robert Boyle who used the apparatus to show that gases were elastic, returning to their original shape after compression. During his experiments he noted that the product of pressure and volume was always the same for a fixed mass of gas at constant pressure. His result, now known as Boyles' Law, was published in 1662. The pressure law and Charles's law followed, with Charles's law named after Jaques Alexandre Cesar Charles, who, whilst working to explain how hot air balloons worked, noted that for a fixed mass of gas at constant pressure, volume was directly proportional to temperature. In 1779, Joseph Lambert used the experimental gas laws to define absolute zero as -273.15°C, the temperature at which the internal energy of a system would be zero.

Key Facts and Principles.

Pressure is a force per unit area. The pressure of a gas depends on volume and tempertature and the behaviour of a gas is sumarised by three gas laws:

Boyle's Law states;

For a fixed mass of gas held at constant temperature, pressure is directly proportional to volume, or

$$PV = constant$$

Where P is the pressure and V is the volume of the gas.

A change at a constant temperature is known as an ***isothermal*** change.

Charles's Law states that for a gas at constant pressure, volume is directly proportional to temperature, or

$$Volume = constant \times Temperature$$

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

Note that in all gas calculations, the temperature *MUST* be in Kelvin.

The **Pressure Law** (also called Gay-Lussac's Law) states

For a fixed mass of gas at constant volume V,

$$\frac{P}{T} = a\ constant$$

Where P is the pressure of the gas and T is the temperature of the gas in Kelvin.

The density of a gas varies depending on the type of gas. When two or more gases are at the same temperature and pressure, the number of atoms (or molecules in the generalised case) in each gas must be the same.

Avogadro's number is based upon the number of atoms in 12g of the isotope Carbon-12. Since there are 602,214,150,000,000,000,000,000 atoms in 12g of Carbon-12,

Avogadro's Number (N_A) is defined as the number of atoms in 12g of the carbon isotope ${}^{12}_{6}C$.

$$N_A = 6.023 \times 10^{23}$$

One ***mole*** of a substance is any substance that contains N_A identical particles. The unit of the molar mass is the kilogram per mole, or in symbols $kgmol^{-1}$. For calculations using the mole;

- The number of moles n in a mass m of a substance is

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

where M is the molar mass of that substance.

- The number of molecules in a mass m of a substance is therefore

$$number\ of\ molecules\ N = N_A \frac{m}{M}$$

An ideal gas is not a real gas but a theoretical gas comprising of identical particles that undergo purely elastic collisions (no loss of momentum or kinetic energy when the particles interact). An ideal gas obeys all the gas laws perfectly, and most real gasses under normal conditions can be approximated to an ideal gas. The theoretical model of an ideal gas tends to fail only at low temperatures or high pressures, when intermolecular forces between gas molecules become significant.

Since an ideal gas obeys Boyle's Law, Charles' Law and the Pressure Law, the three laws may be combined into a relationship that encompasses the volume temperature or pressure of a fixed mass of gas;

$$\frac{PV}{T} = a\ constant$$

where P= pressure in Pa, V = volume in m^3 and T = temperature in °K

The combined gas law shows us that for a fixed mass of gas, the ratio of the product of pressure and volume with temperature is always the same, allowing us to preform 'before and after' calculations.

Since mass is conserved and the air behaves as an ideal gas,

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

The ***ideal gas equation*** for a volume V of n moles of an ideal gas at a temperature T in kelvin and a pressure P in Pascal's is given by;

$$PV = nRT$$

where R = the molar gas constant = $8.31 Jmol^{-1}K^{-1}$

Glossary

Absolute Zero – The lowest temperature that is theoretically possible, at which the motion of particles which constitutes heat would be zero. This temperature is 0° on the Kelvin scale, and equivalent to −273.15° on the Celsius scale.

Avogadro's Number – An amount comprising of 6.022×10^{23} elements, or the number of carbon atoms in 12g of carbon-12

Equilibrium (thermal) – The condition under which two substances in physical contact with each other exchange no heat energy. Two substances in thermal equilibrium are said to be at the same temperature.

Fluid – Comprising of either a gas, or a liquid

Ice point – The temperature at which liquid water at atmospheric pressure solidifies to form ice (0°C or 273K)

Intermolecular – existing or acting between molecules

Internal energy – The sum of kinetic and potential energies of the individual atoms or molecules in a substance

Isothermal – A change in a system (for example a change in pressure, volume or both) where temperature remains a constant during the change

Mole - the unit of measurement in the International System of Units (SI) for amount of substance. It is defined as the amount of a chemical substance that contains as many elementary entities, e.g., atoms, molecules, ions, electrons, or photons, as there are atoms in 12 grams of carbon-12. This number is expressed by the Avogadro constant, which has a value of 6.022×10^{23}

Steam point – The temperature at which liquid water at atmospheric pressure boils to form steam (100°C or 373K)