OCR A Level Physics

Your notes

Ideal Gases

Contents

Your notes

The Avogadro Constant

Avogadro's Constant

- The atomic mass unit (u) is approximately the mass of a proton or neutron = 1.66×10^{-27} kg
- This means that the mass of an atom or molecule can be calculated using the number of protons and neutrons it contains
  - For example, a carbon-12 atom has a mass of:

$$12 \text{ u} = 12 \times 1.66 \times 10^{-27} = 1.99 \times 10^{-26} \text{ kg}$$

The Mole

- In thermodynamics, the amount of substance is measured in the SI unit 'mole'
  - This has the symbol **mol**
  - The mole is a unit of **substance**, not a unit of mass
- The mole is defined as:

  The SI base unit of an 'amount of substance'. It is the amount containing as many particles (e.g., atoms or molecules) as there are atoms in 12 g of carbon-12

- The mole is an important unit in thermodynamics
- If we consider the number of moles of two different gases under the same conditions, their physical properties are the same
- One mole of a substance is defined as the number of molecules in exactly 12 g of carbon:

$$1 \text{ mole} = \frac{0.012}{1.99 \times 10^{-26}} = 6.02 \times 10^{23} \text{ molecules}$$

Avogadro's Constant

Avogadro's constant (N_A) is defined as:

The number of atoms of carbon-12 in 12 g of carbon-12; equal to 6.02×10^{23} mol^{-1}

- For example, 1 mole of sodium (Na) contains 6.02×10^{23} **atoms** of sodium
- The number of atoms can be determined if the number of moles is known by multiplying by N_A.

- For example: 2.0 mol of nitrogen contains: $2.0 \times N_A = 2.0 \times 6.02 \times 10^{23}$ = **1.20×10^{24}** atoms

Molar Mass

- The molar mass of a substance is the mass, in grams, in one mole
  - Its unit is **g mol^{-1}**
- The number of moles from this can be calculated using the equation:

$$\text{Number of moles} = \frac{mass\ (g)}{molar\ mass\ (g\ mol^{-1})}$$

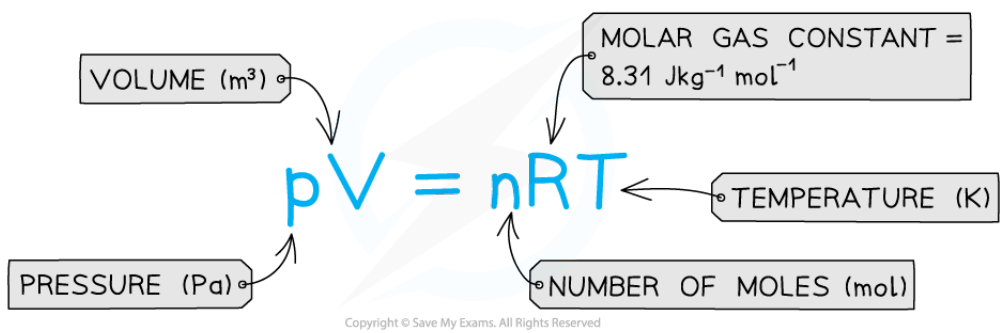
Your notes

Your notes

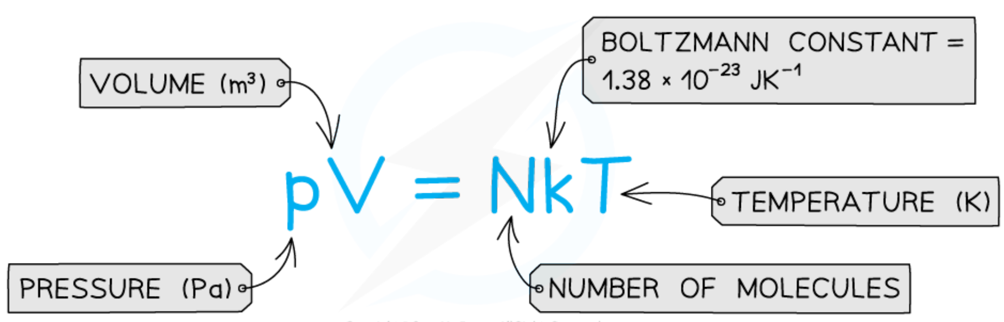
Ideal Gas Equation

Ideal Gas Equation

- An ideal gas is a specific type of gas which:
  - Has molecules with negligible volume
  - Collisions which are elastic
  - Cannot be liquified
  - Has no interactions between the molecules (except during collisions)
  - Obeys the (ideal) gas laws (Boyles law, Charles' law and Pressure law)
- All of these can occur at any temperature or pressure
- The ideal gas equation for number of moles can be expressed as:



- The ideal gas equation for number of molecules can also be written in the form:



- An ideal gas is therefore defined as:

A gas which obeys the equation of state pV = nRT at all pressures, volumes and temperatures

Your notes

Worked Example

A storage cylinder of an ideal gas has a volume of 8.3×10^3 cm^3. The gas is at a temperature of 15 °C and a pressure of 4.5×10^7 Pa.

Calculate the amount of gas in the cylinder, in moles.

Answer:

Step 1: State the known quantities

- Pressure, P = 4.5×10^7 Pa
- Volume, V = 8.3×10^3 cm^3 = $8.3 \times 10^3 \times 10^{-6}$ = 8.3×10^{-3} m^3
- Temperature, T = 15 °C = 15 + 273 = 288 K

Step 2: Write down the ideal gas equation

$$pV = nRT$$

Step 3: Rearrange for the number of moles n

$$n = \frac{pV}{RT}$$

Step 4: Substitute in values and calculate number of moles of gas

$$n = \frac{4.5 \times 10^7 \times 8.3 \times 10^{-3}}{8.31 \times 288} = 160 \text{ mol}$$

Examiner Tips and Tricks

Don't worry about remembering the values of R and k, they will both be given in the equation sheet in your exam.

Gas Laws

Your notes

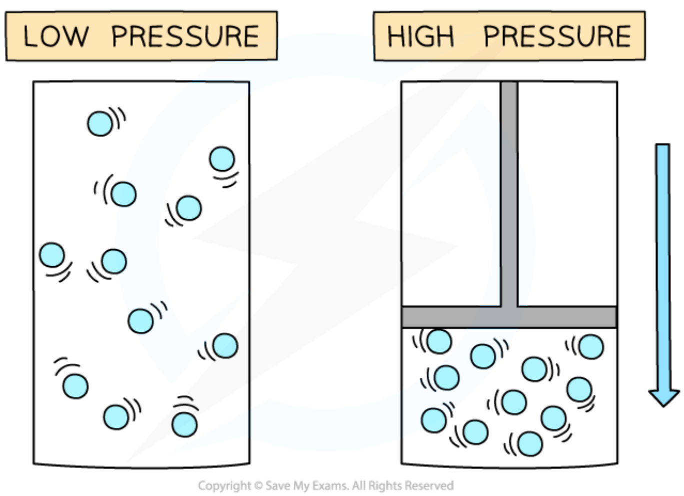
Investigating Gas Laws

Boyle's Law

- If the temperature *T* of an ideal gas is constant, then **Boyle's Law** is given by:

$$P \propto \frac{1}{V}$$

- This means the pressure is **inversely proportional** to the volume of a gas



Pressure increases when a gas is compressed

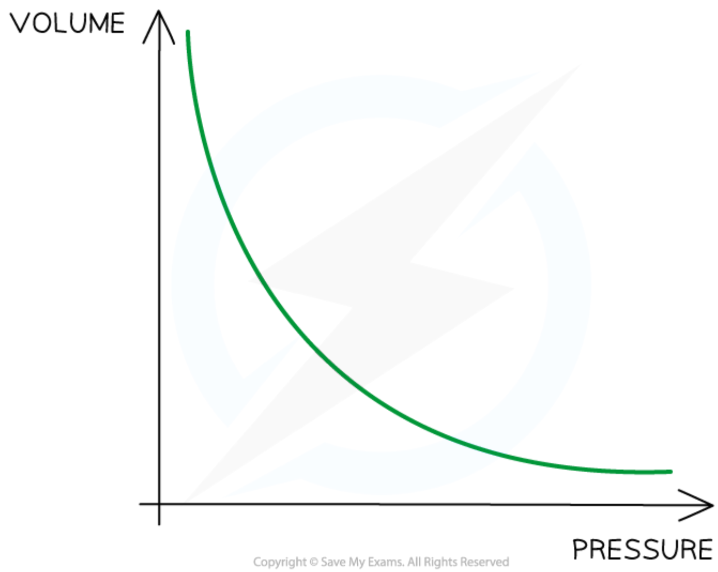
- The relationship between the pressure and volume for a fixed mass of gas at constant temperature can also be written as:

$$P_1V_1 = P_2V_2$$

- Where:
  - P_1 = initial pressure (Pa)
  - P_2 = final pressure (Pa)
  - V_1 = initial volume (m^3)

Your notes

- V_2 = final volume (m^3)



Boyle's Law graph representing pressure inversely proportional to volume

- If the temperature increases, the graph is further from the origin and vice versa

Pressure Law

- If the volume V of an ideal gas is constant, the **Pressure law** is given by:

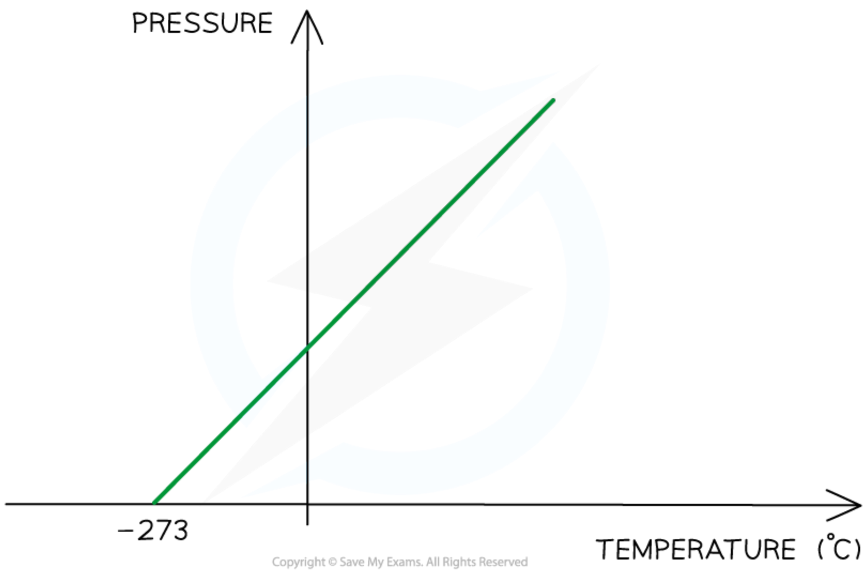
$$P \propto T$$

- This means the pressure is **proportional** to the temperature
- The relationship between the pressure and thermodynamic temperature for a fixed mass of gas at constant volume can also be written as:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

- Where:
  - P_1 = initial pressure (Pa)
  - P_2 = final pressure (Pa)
  - T_1 = initial temperature (K)

- T_2 = final temperature (K)



Pressure Law graph representing temperature (in °C) directly proportional to the volume

Your notes

Worked Example

The pressure inside a bicycle tyre is 5.10×10^5 Pa when the temperature is 279 K. After the bicycle has been ridden, the temperature of the air in the tyre is 299 K.

Calculate the new pressure in the tyre, assuming the volume is unchanged.

Answer:

Step 1: Choose which ideal gas law to use

Since the volume is constant, the pressure law must be used

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Step 2: Write down the known quantities

$P_1 = 5.10 \times 10^5$ Pa

$P_2 = ?$

$T_1 = 279$ K

$T_2 = 299$ K

Step 3: Substitute values into pressure law equation

$$P_2 = \frac{P_1 T_2}{T_1} = \frac{\left(5.10 \times 10^5\right) \times 299}{279} = 5.47 \times 10^5 \text{ Pa}$$

Examiner Tips and Tricks

Remember when using any ideal gas law, including the ideal gas equation, the temperature *T* must always be in **kelvin** (K)

Estimating Absolute Zero

- The value of **absolute zero** can be estimated by using the gas law **Charles' Law**
- If the pressure *P* of an ideal gas is constant, then **Charles's law** is given by:

$$V \propto T$$

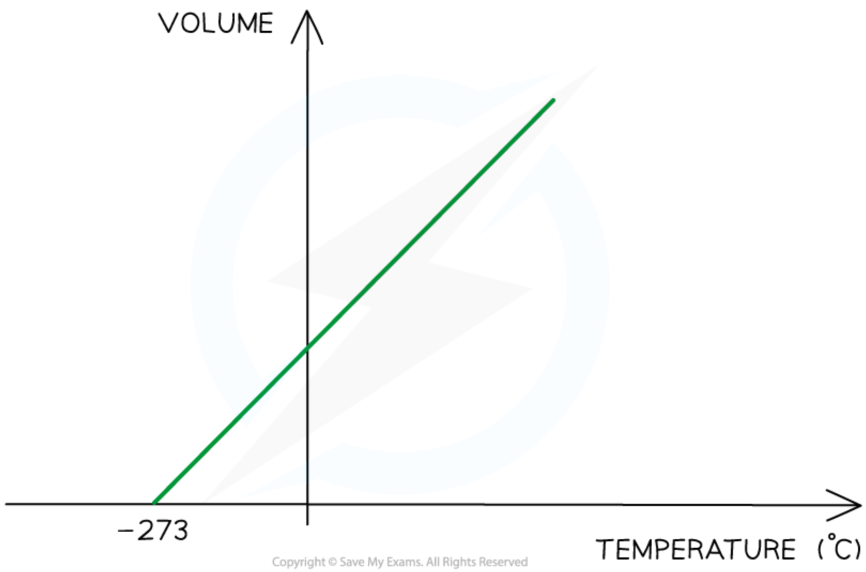
- This means the volume is **proportional** to the temperature of a gas
- The relationship between the volume and thermodynamic temperature for a fixed mass of gas at constant pressure can also be written as:

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

Your notes

Your notes

- Where:
  - V_1 = initial volume (m^3)
  - V_2 = final volume (m^3)
  - T_1 = initial temperature (K)
  - T_2 = final temperature (K)



Charles's Law graph representing temperature (in °C) directly proportional to the volume

- The Charles's Law graph for temperature in **Kelvin** against volume is identical except that it is a straight line through the **origin**
  - Extrapolating backwards leads to a temperature of **absolute zero** at which the gas will have a **volume** of zero m^3