03 The Gaseous State



1 Gases and their Units

1.1 Properties of gases

- Much **lower density** than solids and liquids
- Take the **volume and shape** of the container
- Highly **compressible**, exert pressure equally in all directions

Pressure: the force exerted by gas particles colliding with a surface, _____. p ↑ with n ↑, T ↑ and V ↓.

1.2 S.I. units and conversions

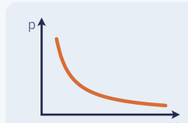
Quantity	S.I. unit	Conversions
pressure, p	**Pa** (N m^{-2})	1 atm = 101 325 Pa = 760 mm Hg, 1 bar = 10^5 Pa
volume, V	**m^3**	1 dm^3 = 1 L = 10^{-3} m^3, 1 cm^3 = 1 mL = _____ m^3
temperature, T	**K**	T / K = T / °C + _____
amount, n	**mol**	n = mass / M_r

2 The Gas Laws

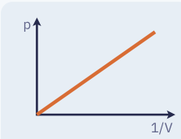
Boyle's law (fixed n, T)

At constant temperature, the volume of a fixed mass of gas is _____ to its pressure.

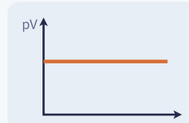
$pV = k \quad p_1V_1 = p_2V_2$



p against V



p against 1/V



pV against p

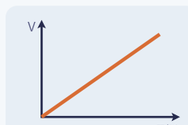
WORKED EXAMPLE: BOYLE A balloon holds 600 cm^3 of gas. Its pressure falls to one-third at constant temperature. Find its new volume.

$p(600) = (p/3)V_2 \rightarrow V_2 =$ _____

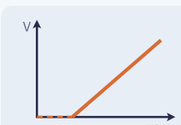
Charles's law (fixed n, p)

The volume of a fixed mass of gas at constant pressure is _____ to its temperature in _____.

$V / T = k \quad V_1/T_1 = V_2/T_2$



V against T / K



V against T / °C

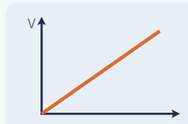
WORKED EXAMPLE: CHARLES 32.0 cm^3 of CO_2 is collected at 0 °C and 1 atm. Find its volume at r.t.p. (20 °C, 1 atm).

$V_2 = 32.0 \times \frac{293}{273} =$ _____ (use kelvin, never °C)

Avogadro's law (fixed p, T)

Under the same temperature and pressure, equal volumes of all gases contain _____ of molecules.

$V / n = k \quad V_1/n_1 = V_2/n_2$



V against n

2 The Gas Laws (continued)

2.1 Explaining the gas laws with kinetic theory

- **Boyle**: V ↓ → particles travel a **shorter distance** between collisions with the walls → less time between collisions → _____ collisions with the walls → p ↑
- **Charles**: T ↑ → particles have higher KE and move faster → hit the walls more often and with _____ → walls move out (V ↑) until p is restored
- **Avogadro / Dalton**: p depends on the no. of collisions per second, which is proportional to the _____

3 The Ideal Gas Equation

$$pV = nRT$$

R = 8.31 J K^{-1} mol^{-1}, all quantities in _____

An **ideal gas** obeys pV = nRT exactly at all pressures and temperatures.

n, T constant	$p \propto 1/V$	Boyle
n, p constant	$V \propto T$	Charles
p, T constant	$V \propto n$	Avogadro
n, V constant	$p \propto T$	

NOTE Two special forms of pV = nRT, derived by substitution

$M_r = \frac{mRT}{pV}$ substitute $n = \frac{m}{M_r}$ into pV = nRT

$\rho = \frac{pM_r}{RT}$ then use density, $\rho = \frac{m}{V}$

WORKED EXAMPLE: M_R OF A GAS 0.10 g of a gas occupies 83.1 cm^3 at 1.0×10^5 Pa and 27 °C. Find its M_r.

$M_r = \frac{mRT}{pV} = \frac{0.10 \times 8.31 \times \square}{1.0 \times 10^5 \times \square}$

= _____

WORKED EXAMPLE: MOLAR VOLUME AT S.T.P. Find the volume of 1 mol of an ideal gas at s.t.p. (0 °C, 1 bar).

$V = \frac{nRT}{p} = \frac{1 \times 8.31 \times 273}{10^5} = 2.27 \times 10^{-2}$

m^3 = _____

WORKED EXAMPLE: DENSITY Find the density of H_2S (M_r 34.1) at 20 °C and 2.00 atm.

$\rho = \frac{pM_r}{RT} = \frac{2.00 \times 101\,325 \times 34.1}{8.31 \times 293}$

= 2840 g m^{-3} = _____

WORKED EXAMPLE: CHANGE OF CONDITIONS A gas at 25 °C is heated until both its pressure and volume double (n constant). Find the final temperature.

$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} \rightarrow T_2 = 4 \times 298 =$ _____

4 Dalton's Law of Partial Pressures

In a mixture of gases that do not react, each gas behaves as if it were _____ present. The total pressure is the _____ of the partial pressures.

$p_{total} = p_A + p_B + \dots$ Total pressure = sum of the partial pressures. **Partial pressure** p_A: the pressure gas A would exert if it _____.

$x_A = n_A / n_{total}$ **Mole fraction** x_A: the fraction of all the gas particles that are A.

$p_A = x_A \times p_{total}$ A's share of the pressure = A's share of the particles.

WORKED EXAMPLE: PARTIAL PRESSURES A cylinder holds 0.5 mol He, 2.0 mol Ne and 2.5 mol Ar at a total pressure of 100 kPa. Find each partial pressure.

1. $n_{total} = 0.5 + 2.0 + 2.5 = 5.0$ mol
2. $x_{He} = 0.5 \div 5.0 = 0.1$
   $x_{Ne} = 2.0 \div 5.0 = 0.4$
   $x_{Ar} = 2.5 \div 5.0 = 0.5$
3. $p_{He} = 0.1 \times 100 =$ _____
   $p_{Ne} = 0.4 \times 100 = 40$ kPa
   $p_{Ar} = 0.5 \times 100 =$ _____

WORKED EXAMPLE: CONNECTING FLASKS A 1 dm³ flask of He at 2 kPa is connected to a 2 dm³ flask of Ne at 1 kPa at constant temperature. Find the final pressure.

1. Each gas spreads through all 3 dm³ as if alone, so $p_1V_1 = p_2V_2$ for each
2. He: $2 \times 1 = p_{He} \times 3$, so $p_{He} = 0.667$ kPa
   Ne: $1 \times 2 = p_{Ne} \times 3$, so $p_{Ne} = 0.667$ kPa
3. $p_{total} = p_{He} + p_{Ne} = 0.667 + 0.667$
   = _____

5 Kinetic Theory of Gases

5.1 Assumptions for an ideal gas

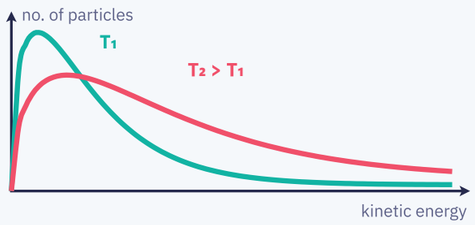
1. Gas particles have _____ compared to the volume of the container (point masses)
2. Gas particles exert _____ on one another
3. Collisions between particles are perfectly _____ → no loss of kinetic energy
4. Particles are in constant, _____ motion

Average kinetic energy of the particles ∝ T (in kelvin). The first two are the **2 main features** of an ideal gas.

5.2 Maxwell–Boltzmann distribution

When temperature increases

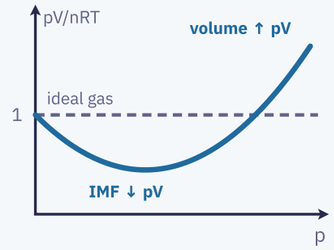
1. The peak shifts to the _____: the most probable speed or energy increases
2. The curve _____: a larger spread of speeds, more particles at high speeds
3. The area under the curve stays _____: the total no. of particles is unchanged



6 Real Gases

6.1 Deviation from ideality

For an ideal gas pV / nRT = 1 at all p. Real gases deviate most at **high p** and **low T**, because of (1) **IMF** between particles and (2) the **volume of the particles**.



↓ Dip: IMF significant

1. A particle about to hit the wall is _____ by the particles around it
2. → hits the wall with less force → p lower than ideal → pV ↓

↑ Rise at high p: particle volume significant

1. Volume of the gas particles is no longer negligible compared to the _____
2. → volume of real gas > ideal gas → pV ↑

WORKED EXAMPLE Rank CH_4, HCl and HF in order of decreasing ideality at the same conditions.

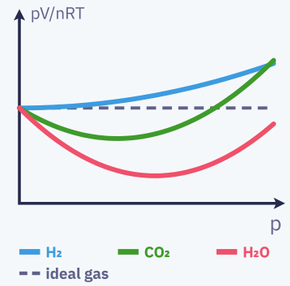
1. CH_4 has only weak id–id, HCl has _____, HF has strong _____
2. Stronger IMF → greater deviation → ideality: CH_4 > HCl > HF

6.2 Conditions for ideal behaviour

1. **Low pressure**: the gas occupies a large volume, so the volume of the particles is _____ compared to the container. Particles are far apart, so IMF are negligible
2. **High temperature**: particles have high _____, enough to overcome the IMF

6.3 Effect of IMF

- Stronger IMF → greater deviation. H_2O (H bonds) > CO_2 > H_2 (weak id–id). H_2's id–id are so weak that its pV never dips below the ideal value
- **Polar** molecules: pd–pd or H bonds are stronger than id–id of non-polar molecules of similar M_r
- **Large electron cloud**: stronger, more extensive IMF, and larger particle volume



6.4 Effect of temperature

T ↑ → particles have higher KE and move faster → IMF become _____ → pV approaches the ideal value → less deviation. At very low T the particles move slowly, so IMF dominate and the gas condenses to a liquid, far from ideal.

