

Ideal gases

Structure 1.5 · SL

Why does a sealed can burst in a fire?

Gas pressure is particles hitting the walls; change how often or how hard they hit, and the pressure changes.

- A heated sealed can splits; a pumped tyre gets harder; a blocked syringe pushes back.
- One particle model explains all three.
- This unit: the model $\rightarrow p, V, T$ links $\rightarrow$ **molar volume** and $pV = nRT \rightarrow$ real gases.

Five assumptions of an ideal gas

- Particles move randomly in straight lines between collisions.
- Particle volume is negligible; there are no **intermolecular forces**.
- Collisions are **elastic**; average kinetic energy is proportional to kelvin temperature.

Pressure the force per unit area the particles exert when they hit the walls

Every gas calculation uses kelvin

- The **kelvin scale** starts at **absolute zero**, where particles would have no kinetic energy.
- Kelvin temperature is proportional to average kinetic energy; Celsius is not.

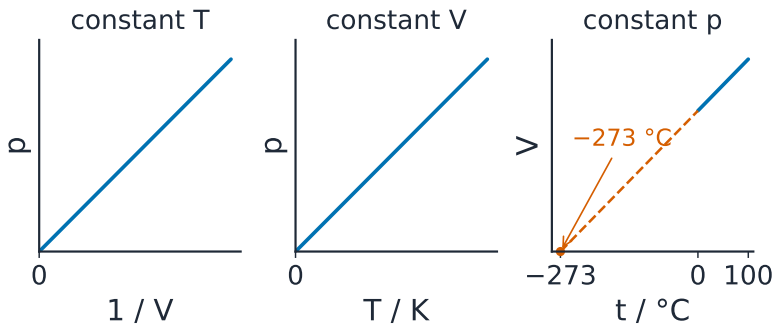
$$T/\text{K} = t/^{\circ}\text{C} + 273$$

400 K is twice 200 K, but 40 °C is not twice 20 °C.

Three relationships for a fixed amount of gas

Held fixed	Relationship	Particle explanation
T	$p \propto 1/V$, so pV is constant	smaller volume $\rightarrow$ more hits on the walls per second
V	$p \propto T$	faster particles hit more often and harder
p	$V \propto T$	faster particles push the walls out until p is back

Straight lines show proportionality



A straight line through the origin means proportional; the V - t line meets zero at **absolute zero**.

Worked example: the combined gas law

1 **Kelvin.** $T_1 = 293 \text{ K}$, $T_2 = 353 \text{ K}$

2 **Rearrange.** $V_2 = \frac{p_1 V_1 T_2}{p_2 T_1}$

3 **Substitute.** $V_2 = \frac{100 \times 250 \times 353}{150 \times 293} = 201 \text{ cm}^3$

Decision

Higher pressure squeezes, higher temperature expands; the effects nearly cancel, so about 200 cm^3 is sensible.

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

Molar volume and Avogadro's law

- Equal volumes of gases at the same T and p contain equal numbers of particles.
- At STP (273 K, 100 kPa) one mole of any ideal gas occupies 22.7 dm³.
- Gas coefficients give volume ratios: $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$ is 10 : 30 : 20 cm³.

$$n = \frac{V}{V_m} \quad V_m = 22.7 \text{ dm}^3 \text{ mol}^{-1}$$

The ideal gas equation and its units

Quantity	SI unit	Convert from
p	Pa	1 kPa = 10^3 Pa
V	m^3	$1 \text{ dm}^3 = 10^{-3} \text{ m}^3$; $1 \text{ cm}^3 = 10^{-6} \text{ m}^3$
T	K	add 273 to $^{\circ}\text{C}$

Use the evidence

Never mix kPa with m^3 .

Worked example: a molar mass from gas data

1 Convert. $p = 1.00 \times 10^5 \text{ Pa}$, $V = 1.80 \times 10^{-4} \text{ m}^3$

2 Amount. $n = \frac{pV}{RT} = \frac{1.00 \times 10^5 \times 1.80 \times 10^{-4}}{8.31 \times 300} = 7.22 \times 10^{-3} \text{ mol}$

3 Molar mass. $M = 0.320 / 7.22 \times 10^{-3} = 44.3 \text{ g mol}^{-1}$

Decision

Close to 44.0 g mol^{-1} , so carbon dioxide or propane.

When real gases break the model

High pressure

Particles are close together, so their own volume is not negligible.

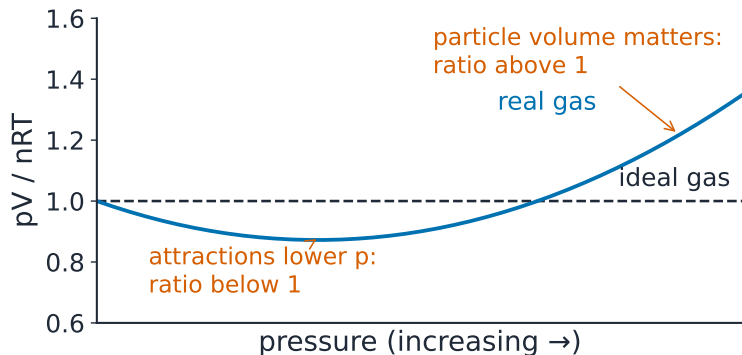
Measured volume is larger than $pV = nRT$ predicts.

Low temperature

Slow particles feel attractions from their neighbours.

They hit the walls less hard, so pressure is lower than predicted.

Measuring the deviation



The further pV/nRT is from 1, the less ideal the gas.

Exam tips

Most lost marks are unit slips. Write the units beside every number you substitute.

- Convert every temperature to kelvin before you substitute.
- In $pV = nRT$ use Pa with m^3 , or kPa with dm^3 .
- "Deviates at high pressure and low temperature" needs the reasons: particle volume and attractions.
- $22.7 \text{ dm}^3 \text{ mol}^{-1}$ is for STP only.

Check yourself

Try these

A gas at 300 K and 120 kPa in a rigid container is cooled to 250 K. Find the new pressure.

Find the volume of 0.0400 mol of gas at STP, in cm^3 .

1.00 g of a gas occupies 0.763 dm^3 at STP. Find its molar mass and suggest the gas.

Explain why heating a gas at constant volume raises its pressure.