Ideal gases

Structure 1.5 · SL

Different ways to change gas pressure

Heating, adding gas and changing volume are different model changes.

- Confinement and construction affect whether a container fails.
- A tyre pump adds gas; a syringe can change volume.
- Explanatory examples are not instructions to heat sealed containers.

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

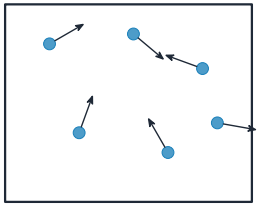
Every gas calculation uses kelvin

- The classical model relates mean translational energy to kelvin T.
- Exact Celsius offset: 273.15; stated whole-kelvin estimates use 273.

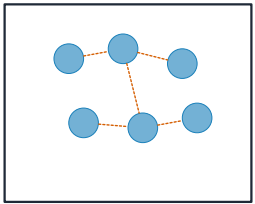
$$T/\mathrm{K} = t/^{\circ}\mathrm{C} + 273.15$$

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

Ideal and real gases



ideal gas (model)
point particles, *no* forces



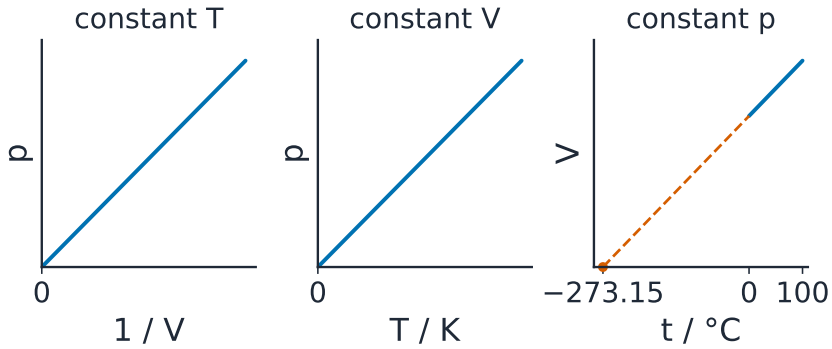
real gas: high p, low T
real size + attractions (dashed)

> Real gases behave ideally at low pressure and high temperature

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



The Celsius intercept is an ideal extrapolation; **real gas** may condense first.

Worked example: the combined gas law

1. **Convert.** 100000 Pa; 150000 Pa; $V_1 = 2.50 \times 10^{-4}$ m^3; T = 293/353 K
2. **Calculate.** $V_2 = p_1V_1T_2/(p_2T_1) = 2.0079636... \times 10^{-4}$ m^3
3. **Check.** Factor $(353/293)/1.50 = 0.803185...$

Decision

201 cm^3: about 19.7% lower volume, rather than cancellation.

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

Molar volume and Avogadro's law

- Equal ideal-gas volumes at the same T,p contain equal numbers of particles.
- The booklet **molar volume** 22.7 $\mathrm{dm}^3/\mathrm{mol}$ applies at its stated STP.
- Gas coefficients give volume ratios only for the stated reaction extent and common conditions.

$$n = \frac{V}{V_m} \qquad V_m = 22.7\ \mathrm{dm}^3\,\mathrm{mol}^{-1}$$

The ideal gas equation and its units

Quantity	SI unit	Convert from
p	Pa	1 kPa $= 10^{3}$ Pa
V	m^3	1 $\mathrm{dm}^3 = 10^{-3}$ m^3; 1 $\mathrm{cm}^3 = 10^{-6}$ m^3
T	K	Exact offset 273.15; use stated rounding

Use the evidence

A gauge reading must first be related to ambient pressure.

Worked example: a molar mass from gas data

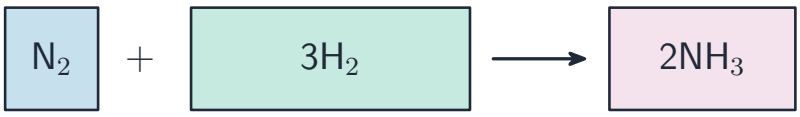
1. **Convert.** $p = 1.00 \times 10^{5}$ Pa, $V = 1.80 \times 10^{-4}$ m^3
2. **Amount.** $n = \dfrac{pV}{RT} = \dfrac{1.00 \times 10^{5} \times 1.80 \times 10^{-4}}{8.31 \times 300} = 7.22 \times 10^{-3}$ mol
3. **Molar mass.** $M = \dfrac{0.320}{7.22 \times 10^{-3}} = 44.3$ g mol^{-1}

Decision

Molar mass alone does not uniquely identify the gas.

Volumes react in mole ratios

40 cm^3 of gas becomes 20 cm^3: volume is not conserved, atoms are



1 : 3 : 2 by volume = 1 : 3 : 2 by moles (same T and p)

> At the same temperature and pressure, volume ratio = mole ratio

When real gases break the model

High pressure

Particle volume can become important.

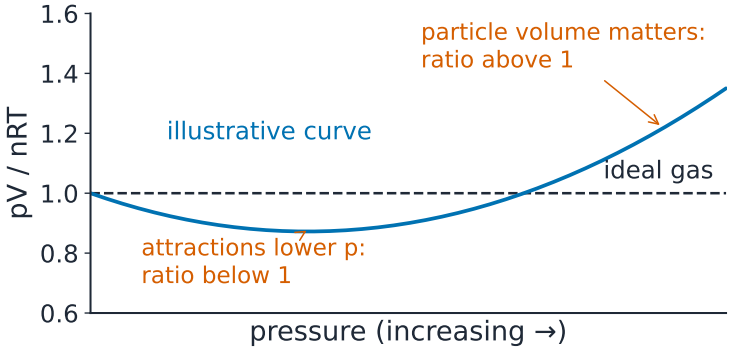
When excluded volume dominates, Z can exceed 1.

Low temperature

Attractions become more important relative to thermal motion.

Condensation can invalidate a single-gas-phase comparison.

Measuring the deviation



Interpret deviation using the conditions and competing effects.

Absolute and gauge pressure

1. **Initial.** Gauge 50 + ambient 100 = 150 kPa absolute
2. **Warm.** Rigid fixed sample: $150 \times 360/300 = 180$ kPa absolute
3. **Gauge.** $180 - 100 = 80$ kPa at unchanged ambient

Decision

Use absolute pressure inside a gas law.

A dry-gas amount

1. **Pressure.** Supplied total 103 − water vapour 3 = 100 kPa
2. **SI.** 100000 Pa; 200 $cm^3 = 2.00 \times 10^{-4}$ m^3
3. **Amount.** n = pV/(RT) = 0.00802246… mol at 300 K

Decision

Check the supplied vapour pressure, levels, leaks and temperature.

Density and molar mass

1. **Model.** $M = \rho RT/p$; use kg/mol with density in kg/m^3
2. **Data.** $\rho = 1.60$ kg/m^3, $T = 300$ K, $p = 100000$ Pa
3. **Result.** $M = 0.039888$ kg/mol $= 39.888$ g/mol

Decision

Report 39.9 g/mol; chemical identity needs independent evidence.

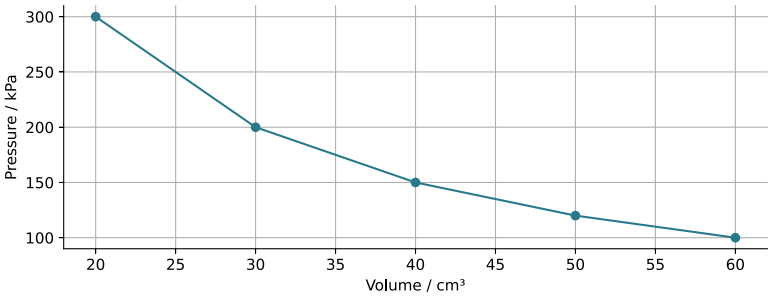
A slope estimates an amount

1. **Line.** p against $1/V$ at fixed amount and T: slope $= nRT$
2. **Units.** Pa / m^{-3} = Pa · m^3 = J
3. **Amount.** $500 / (8.31 \times 300) = 0.2005616\ldots$ mol

Decision

About 0.201 mol, conditional on model and calibration.

Boyle's law in numbers



$pV = 6000$ kPa cm^3 both times

Higher pressure can accompany less gas

1. **Data.** Rigid sample: p 200→204 kPa; T 300→360 K
2. **Ratio.** $n_2/n_1 = (204/200)(300/360) = 0.85$
3. **Meaning.** 15% less amount under the stated model

Decision

A 2% pressure rise does not prove the amount was unchanged.

Exam tips

Show the unit conversion, reference and model conditions.

- Use kelvin and absolute Pa with m^3 for the stated SI **gas constant**.
- Check fixed amount, dry-gas pressure and phase conditions.
- State which molar-volume conditions apply.

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.