Gas Laws

Matthew Williams • Physics • May 20, 2026

Gas Laws

The behaviour of a gas depends on three quantities: **pressure**(P), **volume**(V), and **temperature**(T). The gas laws describe how these three variables are related when one of them is held constant.

All gas law calculations that involve temperature **must** use the Kelvin scale:

$$T(\mathrm{K}) = \theta(^\circ\mathrm{C}) + 273$$

Boyle's Law

Statement: For a fixed mass of gas at **constant temperature**, the pressure is inversely proportional to the volume.

$$P \propto \frac{1}{V} \quad \Longrightarrow \quad PV = \text{constant} \quad \Longrightarrow \quad P_1V_1 = P_2V_2$$

Doubling the pressure halves the volume; tripling the pressure reduces the volume to one-third.

Kinetic theory explanation: Reducing the volume at constant temperature keeps the particle speed the same but puts the particles closer together. They hit the walls more frequently, so pressure increases.

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caption="Boyle's Law: pressure-volume hyperbola at constant temperature. Plotting P vs 1/V gives a straight line through the origin."

height={280}

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Charles' Law

Statement: For a fixed mass of gas at **constant pressure**, the volume is directly proportional to the absolute temperature.

$$V \propto T \quad \Longrightarrow \quad \frac{V}{T} = \text{constant} \quad \Longrightarrow \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

where T is in kelvin. Doubling the absolute temperature doubles the volume.

Kinetic theory explanation: Heating a gas at constant pressure increases the average speed of particles. Faster particles push the walls outward more forcefully, so the volume expands until the pressure returns to its original value.

The Pressure Law (Gay-Lussac's Law)

Statement: For a fixed mass of gas at **constant volume**, the pressure is directly proportional to the absolute temperature.

$$P \propto T \quad \Longrightarrow \quad \frac{P}{T} = \text{constant} \quad \Longrightarrow \quad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Kinetic theory explanation: Raising the temperature at constant volume increases particle speed. Particles hit the walls harder and more often, so pressure increases proportionally with absolute temperature.

The pressure-temperature graph, when plotted in Celsius, is a straight line that, when extrapolated, reaches zero pressure at -273 °C. This is **absolute zero** (0 K), the theoretical temperature at which particles have minimum kinetic energy and gas pressure would cease.

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The General Gas Law

When all three variables change simultaneously for a fixed mass of gas:

$$\frac{PV}{T} = \text{constant} \quad \Longrightarrow \quad \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

The individual gas laws are all special cases of this combined equation.

Boyle's Law, gas in a piston (2015 Paper 02, Q5)

A piston traps gas in a cylinder. At 25 °C, the pressure is 5 atm and the volume is 50 mL.

Part (i), Volume if pressure drops to 1 atm at constant temperature (Boyle's Law):

$$P_1V_1 = P_2V_2$$

$$5 \times 50 = 1 \times V_2$$

$$V_2 = \frac{250}{1} = 250\text{mL}$$

Part (ii), Piston resets to initial conditions. Volume is fixed; gas is heated to 60 °C. Find the new pressure (Pressure Law):

$$T_1 = 25 + 273 = 298 \text{ K}$$

$$T_2 = 60 + 273 = 333 \text{ K}$$

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

$$\frac{5}{298} = \frac{P_2}{333}$$

$$P_2 = \frac{5 \times 333}{298}$$

$$P_2 = \frac{1665}{298}$$

$$P_2 \approx 5.6 \text{ atm}$$

General gas law (2021 Paper 02, Q4)

A container stores 5.0 m^3 of gas at a pressure of 13 atm and a temperature of −23 °C. Calculate the volume the gas would occupy at 27 °C and 1 atm.

Convert temperatures to kelvin:

$$T_1 = -23 + 273 = 250 \text{ K}$$

$$T_2 = 27 + 273 = 300 \text{ K}$$

Apply the general gas law:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{13 \times 5.0}{250} = \frac{1 \times V_2}{300}$$

$$V_2 = \frac{13 \times 5.0 \times 300}{250 \times 1}$$

$$V_2 = \frac{19\,500}{250}$$

$$V_2 = 78 \text{ m}^3$$

📝 **Exam Tip**

Always convert Celsius to kelvin before substituting into any gas law formula. Forgetting this is the most common error in gas law calculations, the mark scheme deducts a mark for using Celsius temperatures directly.

To identify which law applies: if temperature is constant, use Boyle's. If pressure is constant, use Charles'. If volume is constant, use the Pressure Law. If all three change, use the general gas law.