A-LEVEL PHYSICS • EXERCISE SHEET

15.2 Equation of state

Name: ______________ Class: __________ Date: ____________ **Total: 16 marks**

Objective

Build the skills to answer exam questions on the **equation of state** of an ideal gas.

You must be able to:

- use $pV = nRT$ and $pV = NkT$ (with T in kelvin)
- recall R, k and that $k = R/N_A$
- read a pV–T **graph**: gradient $= Nk$, so $N =$ gradient$/k$

1 Worked examples

Study these first. Each one shows the method for a question type used later —follow the steps and you can do the Practice and Exam-style questions yourself.

■ Equation of state

An **ideal gas** obeys $pV \propto T$. Two equal forms:

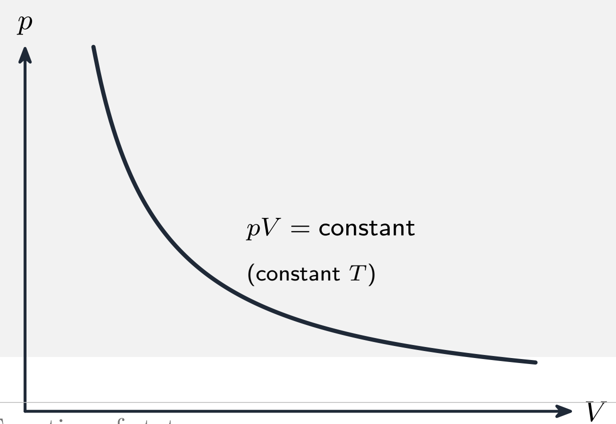
$$pV = nRT \quad (n = \text{moles}), \qquad pV = NkT \quad (N = \text{molecules}),$$

with $R = 8.31$ J mol^{-1} K^{-1}, $k = 1.38 \times 10^{-23}$ J K^{-1}, and $k = R/N_A$. **Always use Pa, m³, K.**

Worked example. 0.50 mol at 300 K in 0.020 m^3: $p = \dfrac{nRT}{V} = \dfrac{0.50 \times 8.31 \times 300}{0.020} = 6.2 \times 10^4$ Pa.

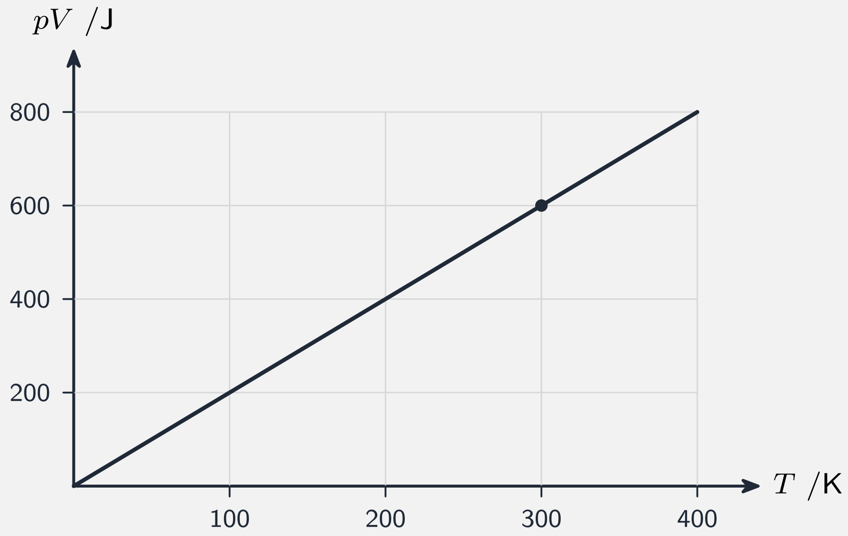
■ Boyle's law

At constant T (and amount), $p \propto 1/V$, so $pV =$ constant:



■ **Reading a pV–T graph**

For a fixed amount of gas, $pV = NkT$, so a graph of pV against T (in kelvin) is a **straight line through the origin** with **gradient** Nk:



A straight line **through the origin** confirms the gas is **ideal** ($pV \propto T$). To find the number of molecules, read the **gradient** and divide by k: $N = \dfrac{\text{gradient}}{k}$.

Worked example. The line above passes through $(300\ \text{K}, 600\ \text{J})$, so gradient $= 600/300 = 2.0\ \text{J K}^{-1} = Nk$; thus $N = \dfrac{2.0}{1.38 \times 10^{-23}} = 1.4 \times 10^{23}$.

2 Practice

Now apply the methods above.

2.1 State what is meant by an **ideal gas**. [1]

2.2 Write the **two** forms of the ideal-gas equation of state. [2]

2.3 State the value of the **molar gas constant** R. [1]

2.4 A graph of pV against T for a fixed mass of ideal gas is a straight line through the origin. State what its **gradient** is equal to. [1]

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3 Exam-style questions

3.1 In $pV = nRT$, the temperature T must be in: [1]

- **A** °C
- **B** K
- **C** J
- **D** mol

3.2 0.50 mol of an ideal gas at 300 K occupies 0.020 m^3. Calculate the **pressure**. ($R = 8.31$.) [3]

3.3 For a fixed mass of gas, the graph of pV against T is a straight line through the origin passing through $(300\ \text{K}, 600\ \text{J})$.

(a) State what this tells you about the gas. [1]

(b) Determine the number of molecules N in the sample. ($k = 1.38 \times 10^{-23}$.) [3]

3.4 State **Boyle's law**. [1]

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4 Go further

You are now ready for the real exam questions on this subtopic. Open the **15.2 Equation of state** past-paper sheet in the Library, or try these in **Practice mode**:

- 9702/42 J25 —Q3 (ideal gas, pV–T graph)
- 9702/41 N25 —Q4 (equation of state)
- 9702/44 J25 —Q3 ($pV = NkT$)
- 9702/43 N25 —Q4 (ideal gas)
- 9702/42 J25 —Q4 (gas laws)

Solutions

2.1 A gas that obeys $pV \propto T$ (i.e. $pV = nRT$) exactly, at all p and T.

2.2 $pV = nRT$ and $pV = NkT$.

2.3 $R = 8.31\ \text{J mol}^{-1}\,\text{K}^{-1}$.

2.4 Nk (the number of molecules $\times$ the Boltzmann constant).

3.1 **B** —kelvin.

3.2 $p = \dfrac{nRT}{V} = \dfrac{0.50 \times 8.31 \times 300}{0.020} = 6.2 \times 10^4$ Pa.

3.3 (a) It is an **ideal gas**: $pV \propto T$ (the line is straight and passes through the origin).

3.3 (b) gradient $= \dfrac{600}{300} = 2.0\ \text{J K}^{-1}$; this equals Nk; $N = \dfrac{2.0}{1.38 \times 10^{-23}} = 1.4 \times 10^{23}$.

3.4 At constant temperature (and amount of gas), the pressure is **inversely proportional** to the volume ($pV =$ constant).