OCR A A Level Ideal Gases 1 solutions

Matching solutions and teaching prompts for the class review

Specification points covered

- 5.1.4(a) Define amount of substance in moles and state the Avogadro constant $N_A = 6.02 \times 10^{23}$ mol^{-1}.
- 5.1.4(d)(i) Use and apply the equation of state of an ideal gas pV = nRT.
- 5.1.4(d)(ii) Apply Boyle's law and pressure-temperature relationships; for a fixed amount of gas, pV/T is constant.
- 5.1.4(g) State and use the Boltzmann constant $k = R/N_A$.
- 5.1.4(h) Use pV = NkT.

Teaching focus

Insist on kelvin, pascals and cubic metres before substitution. Keep n (moles) distinct from N (particles).
Before using pV/T = constant, pupils should say that the amount of gas is fixed. A valve opening or leak breaks that condition.

1. Prepare the data

1. The launch laboratory is at 18.0 °C. Convert this temperature to kelvin. [1 mark]

Answer / mark points: T = 18.0 + 273 = 291 K.	
Teacher prompt / common error: Gas equations require absolute temperature. Do not accept 18.0 K or 255 K.	

2. The rigid calibration chamber has volume 3.60 L. Convert this volume to m^3. [1 mark]

Answer / mark points: $V = 3.60 \times 10^{-3}$ m^3.	
Teacher prompt / common error: 1 L = 10^{-3} m^3. The exponent and the cubic metre unit are both essential.	

3. The initial helium pressure is 125 kPa. Convert this pressure to Pa. [1 mark]

Answer / mark points: $p = 125 \times 10^3 = 1.25 \times 10^5$ Pa.	
Teacher prompt / common error: 1 kPa = 10^3 Pa. Encourage pupils to write the conversion before substitution.	

4. Use $k = R/N_A$ and the data given to calculate the Boltzmann constant k. [1 mark]

Answer / mark points: $k = R/N_A = 8.31/(6.02 \times 10^{23}) = 1.38 \times 10^{-23}$ J K^{-1}.	
Teacher prompt / common error: This relationship connects the molar and particle forms of the gas equation. Require J K^{-1}, not J mol^{-1} K^{-1}.	

2. Moles and particles in the chamber

5. The chamber contains helium at 125 kPa, 3.60 L and 18.0 °C. Calculate the amount of helium n in moles. [1 mark]

Answer / mark points: $n = pV/(RT) = (1.25 \times 10^5 \times 3.60 \times 10^{-3})/(8.31 \times 291) = 0.186$ mol.
Teacher prompt / common error: The calculation is intentionally direct because questions 1-3 have already tested the SI conversions. A Celsius substitution is the key error.

6. Use your answer to question 5 and N_A to calculate the number N of helium atoms in the chamber. [1 mark]

Answer / mark points: $N = nN_A = 0.186088... \times 6.02 \times 10^{23} = 1.12 \times 10^{23}$ atoms.
Teacher prompt / common error: Use the unrounded value of n. N is a count of atoms and has no unit.

7. Use pV = NkT to calculate the number of helium atoms independently. [1 mark]

Answer / mark points: $N = pV/(kT) = (1.25 \times 10^5 \times 3.60 \times 10^{-3})/(1.38 \times 10^{-23} \times 291) = 1.12 \times 10^{23}$ atoms.
Teacher prompt / common error: Pupils must use N, not n, with k. The two equations should give the same particle count.

8. Explain why questions 6 and 7 give the same result, apart from rounding. Your answer should link R, N_A and k. [2 marks]

Answer / mark points: The same gas obeys $pV = nRT$ and $pV = NkT$, so $nR = Nk$. Since $N = nN_A$, it follows that $R = N_Ak$, or $k = R/N_A$. Any small numerical difference is caused by rounding the constants or question 5.
Teacher prompt / common error: The complete link is $N = nN_A$ and $R = N_Ak$. 'They are the same formula' is not enough for both marks.

3. The ground gas-handling rig

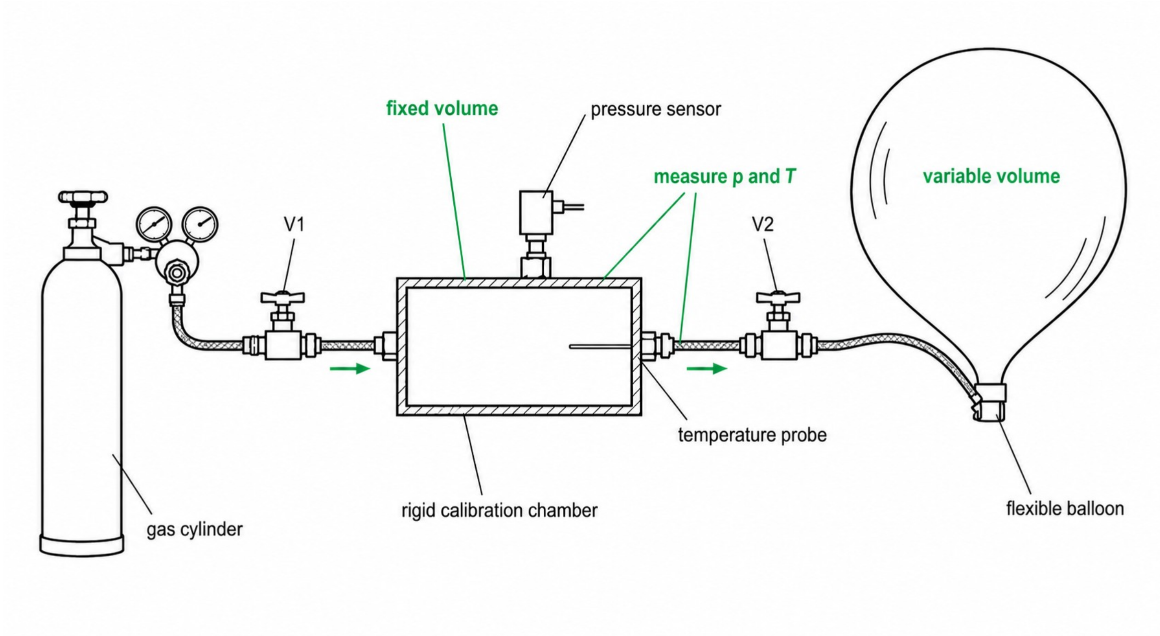

Figure 1: fixed and variable volumes

9. Figure 1 shows the gas-handling rig. State why pV/T = constant may be used to compare two chamber readings only when the valves are closed and no gas enters or leaves. [1 mark]

Answer / mark points: The amount of gas must be fixed. Closing both valves makes the chamber a closed system, so the same number of moles or atoms is present in both readings.
Teacher prompt / common error: The combined gas relationship is a fixed-amount relationship. If gas crosses a valve, n and N change.

10. Both valves are closed. The helium in the rigid chamber warms from 291 K to 328 K. Its initial pressure is 125 kPa. Calculate the final pressure. [1 mark]

Answer / mark points: At fixed volume, p/T is constant. $p_2 = p_1T_2/T_1 = 125 \times 328/291 = 141$ kPa.
Teacher prompt / common error: For a rigid sealed vessel, V and n are constant, leaving p/T constant. Kelvin is already supplied.

11. In another fixed-volume test, the pressure increases from 125 kPa at 291 K to 136 kPa. Calculate the final temperature in °C. [2 marks]

Answer / mark points: $T_2 = T_1p_2/p_1 = 291 \times 136/125 = 316.6$ K. Temperature = 316.6 - 273 = 43.6 °C.
Teacher prompt / common error: Award the kelvin result first, then the conversion to °C. Do not subtract 273 before applying the gas relationship.

4. Expansion, loss and ascent

12. The chamber is at 160 kPa and 291 K. Valve V2 is opened to an initially empty flexible balloon. The temperature remains 291 K and the final pressure is 104 kPa. The hose volume is negligible. Calculate the final volume of the balloon. [2 marks]

Answer / mark points: The temperature and amount of gas are constant, so $p_1V_1 = p_2V_2$. Total final volume = 160 × 3.60/104 = 5.54 L. Balloon volume = 5.54 - 3.60 = 1.94 L.

Teacher prompt / common error: V_2 is the total gas volume after V2 opens: chamber plus balloon. Pupils must subtract the unchanged chamber volume.

13. After the chamber is sealed again, 4.0% of its helium atoms escape through a faulty joint. The chamber volume and gas temperature remain constant. Calculate the new pressure from an initial value of 125 kPa. [1 mark]

Answer / mark points: At fixed V and T, p is proportional to N. p_2 = 0.960 × 125 = 120 kPa.

Teacher prompt / common error: With V and T fixed, p follows the fraction of particles remaining. Four percent lost means 96%, not 4%, of the original pressure.

14. At launch, a sealed research balloon has volume 8.40 m^3, pressure 102 kPa and temperature 295 K. At altitude its pressure is 35.0 kPa and its temperature is 245 K. Calculate its volume at altitude before any gas is vented. [2 marks]

Answer / mark points: $p_1V_1/T_1 = p_2V_2/T_2$, so $V_2 = p_1V_1T_2/(T_1p_2)$ = (102 × 8.40 × 245)/(295 × 35.0) = 20.3 m^3.

Teacher prompt / common error: All three quantities change. A useful check is that the much lower pressure produces a substantially larger volume despite cooling.

15. Calculate the percentage increase in the balloon volume between launch and altitude. [1 mark]

Answer / mark points: Percentage increase = (20.3308... - 8.40)/8.40 × 100 = 142%.

Teacher prompt / common error: Percentage increase is change divided by the initial value. Dividing by the final volume is a common error.

5. Particle count and balloon safety

16. Calculate the amount of helium in the balloon at launch, in moles. [1 mark]

Answer / mark points: $n = pV/(RT) = (102 \times 10^3 \times 8.40)/(8.31 \times 295) = 3.50 \times 10^2$ mol.	
Teacher prompt / common error: This is a direct application of $pV = nRT$ using launch data. Pressure must be in pascals.	

17. Use $pV = NkT$ and your altitude volume from question 14 to calculate the number of helium atoms in the sealed balloon. [1 mark]

Answer / mark points: $N = pV/(kT) = (35.0 \times 10^3 \times 20.3308...)/(1.38 \times 10^{-23} \times 245) = 2.10 \times 10^{26}$ atoms.	
Teacher prompt / common error: Use the unrounded altitude volume. The result should agree with nN_A from question 16 because the balloon is still sealed.	

18. The balloon's maximum safe volume is 19.0 m^3. Calculate the external pressure at which it reaches this volume if its temperature is 245 K and no gas has yet been vented. [1 mark]

Answer / mark points: $p_2 = p_1V_1T_2/(T_1V_2) = (102 \times 8.40 \times 245)/(295 \times 19.0) = 37.5$ kPa.	
Teacher prompt / common error: This is the pressure at which the relief system must begin operating. The volume is larger than at launch, so the pressure should be below 102 kPa.	

19. A relief valve holds the balloon at 19.0 m^3 by venting gas. At 35.0 kPa and 245 K, calculate the percentage of the original helium atoms that have been vented. Use your answer to question 17. [2 marks]

Answer / mark points: Atoms remaining $= pV/(kT) = (35.0 \times 10^3 \times 19.0)/(1.38 \times 10^{-23} \times 245) = 1.97 \times 10^{26}$. Percentage vented $= (2.1046 \times 10^{26} - 1.9669 \times 10^{26})/(2.1046 \times 10^{26}) \times 100 = 6.55\%$.	
Teacher prompt / common error: Once gas vents, the fixed-amount combined law cannot connect launch and final states. Calculate N in each state, then compare.	

6. The sealed sample canister

20. A rigid 1.80 L sample canister is sealed at altitude with argon at 36.0 kPa and 248 K. Calculate its pressure after descent when the gas reaches 303 K. [1 mark]

Answer / mark points: At fixed volume, $p_2 = p_1T_2/T_1 = 36.0 \times 303/248 = 44.0$ kPa.
Teacher prompt / common error: A rigid sealed canister has fixed V and N, so p/T is constant. The warmer gas has the greater pressure.

21. At 303 K, the canister pressure falls from 44.0 kPa to 41.8 kPa while its volume remains constant. Calculate the percentage of the argon atoms that have escaped. [1 mark]

Answer / mark points: At fixed V and T, N is proportional to p. Percentage escaped = $(44.0 - 41.8)/44.0 \times 100 = 5.00\%$.
Teacher prompt / common error: After the temperature stabilises, the pressure ratio is the particle-number ratio. This is a one-operation percentage calculation.

22. A technician claims that the pressure fall in question 21 could be caused by the gas cooling rather than by a leak. The temperature record remains constant at 303 K. Evaluate the claim using the gas relationships. [2 marks]

Answer / mark points: The claim is not supported. The temperature and volume are both constant, so $pV = NkT$ gives p proportional to N. A decrease in pressure therefore shows that the number of argon atoms has decreased; the recorded data indicate a leak, not cooling.
Teacher prompt / common error: Require both controlled quantities: fixed volume and constant temperature. Then use p proportional to N to reject the cooling explanation.

23. The canister has a maximum safe pressure of 55.0 kPa. Starting from 44.0 kPa at 303 K, calculate the maximum safe gas temperature in °C if the canister does not leak. [2 marks]

Answer / mark points: $T_2 = T_1p_2/p_1 = 303 \times 55.0/44.0 = 378.75$ K. Temperature = 378.75 - 273 = 106 °C.
Teacher prompt / common error: The gas-law calculation gives kelvin. A final conversion to °C is required because the question requests °C.

7. Emergency pouch and gas density

24. An emergency instrument pouch contains 3.50×10^{22} nitrogen molecules at 265 K in a volume of 4.80 L. Calculate the pressure inside the pouch. **[1 mark]**

Answer / mark points: $p = NkT/V = (3.50 \times 10^{22} \times 1.38 \times 10^{-23} \times 265)/(4.80 \times 10^{-3}) = 2.67 \times 10^{4}$ Pa = 26.7 kPa.	
Teacher prompt / common error: Use the particle equation because N is given. Convert 4.80 L to 4.80×10^{-3} m^3.	

25. At the same temperature and volume, calculate the number of additional molecules required to raise the pouch pressure to 40.0 kPa. **[2 marks]**

Answer / mark points: $N_{final} = pV/(kT) = (40.0 \times 10^{3} \times 4.80 \times 10^{-3})/(1.38 \times 10^{-23} \times 265) = 5.25 \times 10^{22}$. Additional molecules = $5.25 \times 10^{22} - 3.50 \times 10^{22} = 1.75 \times 10^{22}$.	
Teacher prompt / common error: Find the target total number first, then subtract the number already present. Reporting 5.25×10^{22} gives only the target, not the addition.	

26. The molar mass of a gas is M and its mass is m. Starting from pV = nRT, together with m = nM and ρ = m/V, show that ρ = pM/(RT). **[3 marks]**

Answer / mark points: From pV = nRT, n = pV/(RT). Since m = nM, m = pVM/(RT). Therefore ρ = m/V = [pVM/(RT)]/V = pM/(RT).	
Teacher prompt / common error: For all three marks, expect the ideal-gas starting equation, substitution using m = nM, and cancellation of V to reach the stated expression. Do not set n = 1.	

27. Use the expression from question 26 to calculate the density of helium at 35.0 kPa and 245 K. The molar mass of helium is 4.00×10^{-3} kg mol^{-1}. **[1 mark]**

Answer / mark points: $\rho = pM/(RT) = (35.0 \times 10^{3} \times 4.00 \times 10^{-3})/(8.31 \times 245) = 6.88 \times 10^{-2}$ kg m^{-3}.	
Teacher prompt / common error: Molar mass must be in kg mol^{-1}. The low density is physically reasonable for helium at low pressure.	

Language check

Use 'pressure increases', 'volume decreases' and 'temperature stays constant'. Do not say that a pressure or volume 'accelerates'. State the controlled quantities before simplifying a gas equation: fixed V, fixed T or fixed amount of gas.