

1

- (a) State **two** assumptions made about the **motion** of the molecules in a gas in the derivation of the kinetic theory of gases equation.

(2)

- (b) Use the kinetic theory of gases to explain why the pressure inside a football increases when the temperature of the air inside it rises. Assume that the volume of the ball remains constant.

(3)

- (c) The 'laws of football' require the ball to have a circumference between 680 mm and 700 mm. The pressure of the air in the ball is required to be between 0.60×10^5 Pa and 1.10×10^5 Pa above atmospheric pressure.

A ball is inflated when the atmospheric pressure is 1.00×10^5 Pa and the temperature is 17 °C. When inflated the mass of air inside the ball is 11.4 g and the circumference of the ball is 690 mm.

Assume that air behaves as an ideal gas and that the thickness of the material used for the ball is negligible.

Deduce if the inflated ball satisfies the law of football about the pressure.

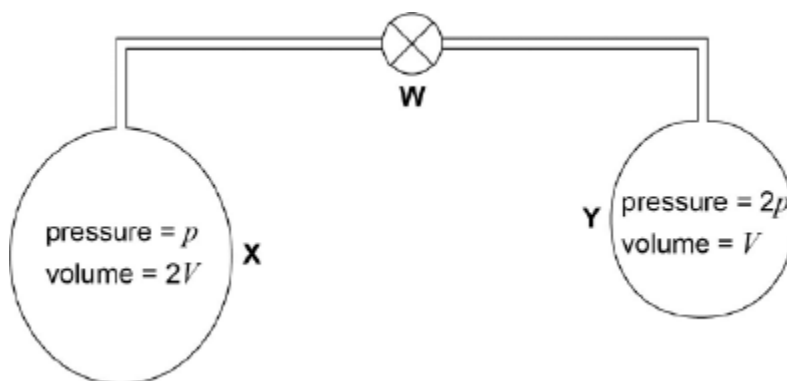
molar mass of air = 29 g mol^{-1}

(6)

(Total 11 marks)

2

X and **Y** are two gas bottles that are connected by a tube that has negligible volume compared with the volume of each bottle.



Initially the valve **W** is closed.

X has a volume $2V$ and contains hydrogen at a pressure of p .

Y has a volume V and contains hydrogen at a pressure of $2p$.

X and **Y** are both initially at the same temperature.

W is now opened. Assuming that there is no change in temperature, what is the new gas pressure?

A $\frac{2}{3}p$ ☐

B $\frac{5}{3}p$ ☐

C $\frac{4}{3}p$ ☐

D $\frac{3}{2}p$ ☐

(Total 1 mark)

3

- (a) 'The pressure of an ideal gas is inversely proportional to its volume', is an incomplete statement of Boyle's law.

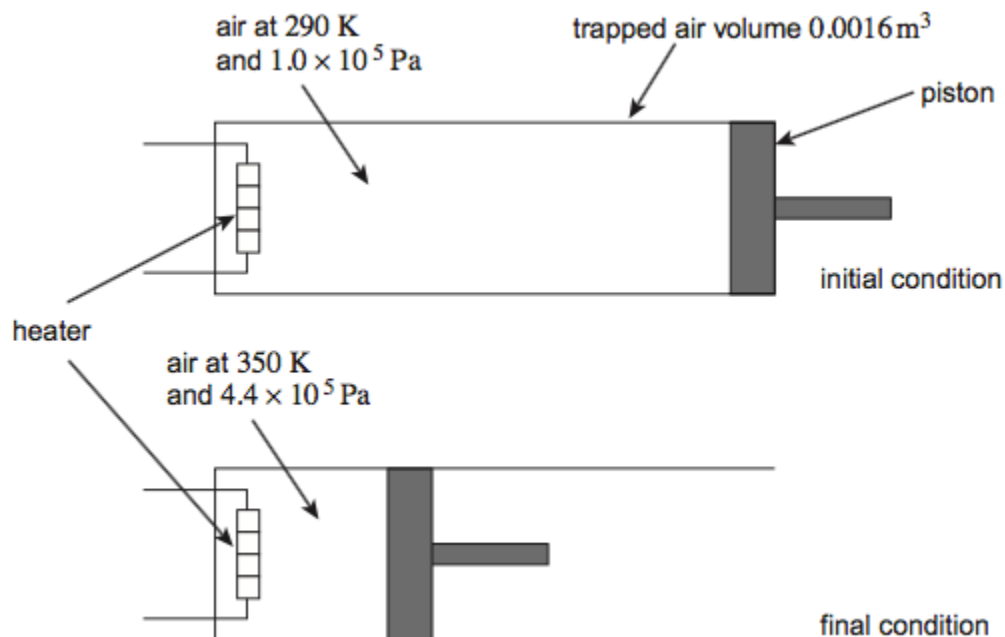
State **two** conditions necessary to complete the statement.

1. _____

2. _____

(2)

- (b) A volume of 0.0016 m^3 of air at a pressure of $1.0 \times 10^5 \text{ Pa}$ and a temperature of 290 K is trapped in a cylinder. Under these conditions the volume of air occupied by 1.0 mol is 0.024 m^3 . The air in the cylinder is heated and at the same time compressed slowly by a piston. The initial condition and final condition of the trapped air are shown in the diagram.



In the following calculations treat air as an ideal gas having a molar mass of $0.029 \text{ kg mol}^{-1}$.

- (i) Calculate the final volume of the air trapped in the cylinder.

volume of air = _____ m^3

(2)

- (ii) Calculate the number of moles of air in the cylinder.

number of moles = _____

(1)

- (iii) Calculate the initial density of air trapped in the cylinder.

density = _____ kg m^{-3}

(2)

- (c) State and explain what happens to the speed of molecules in a gas as the temperature increases.

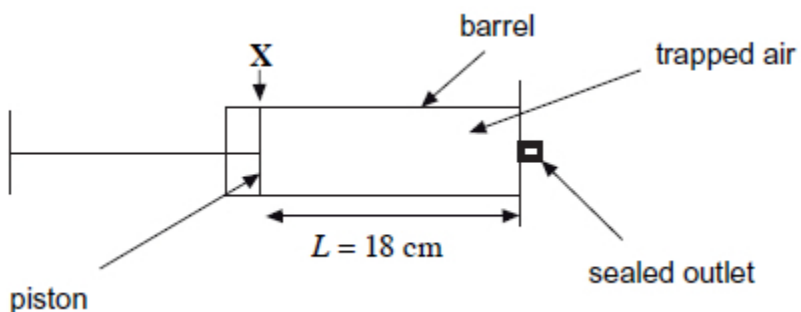
(2)

(Total 9 marks)

4

Figure 1 shows the cross-section of a bicycle pump with a cylindrical barrel. The piston has been pulled to the position marked **X** and the outlet of the pump sealed.

Figure 1



The length L of the column of trapped air is 18 cm and the volume of the gas is $1.7 \times 10^{-4} \text{ m}^3$ when the piston is at position **X**. Under these conditions the trapped air is at a pressure p of $1.01 \times 10^5 \text{ Pa}$ and its temperature is 19°C .

Assume the trapped air consists of identical molecules and behaves like an ideal gas in this question.

- (a) (i) Calculate the internal diameter of the barrel.

diameter _____ m

(2)

- (ii) Show that the number of air molecules in the column of trapped air is approximately 4×10^{21} .

(3)

- (iii) The ratio $\frac{\text{total volume of the air molecules}}{\text{volume occupied by the column of trapped air}}$ equals 7.0×10^{-4} .

Calculate the volume of one air molecule.

volume _____ m^3

(2)

- (iv) The ratio in part **(a)(iii)** is important in supporting assumptions made in the kinetic theory of ideal gases.

Explain how the value of the ratio supports **two** of the assumptions made in the kinetic theory of ideal gases.

(3)

- (b) The mass of each air molecule is 4.7×10^{-26} kg.

Calculate the mean square speed of the molecules of trapped air when the length of the column of trapped air is 18.0 cm.

Give an appropriate unit for your answer.

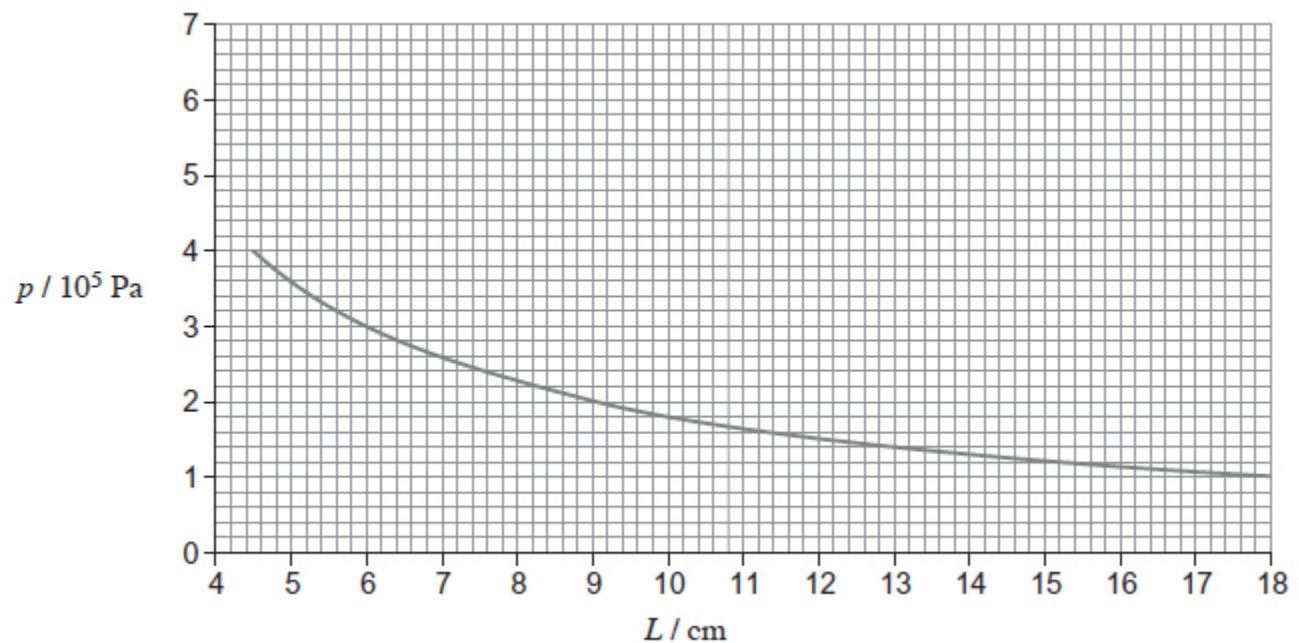
mean square speed _____ unit _____

(4)

- (c) The piston is pushed slowly inwards until the length L of the column of trapped air is 4.5 cm.

Figure 2 shows how the pressure p of the trapped air varies as L is changed during this process.

Figure 2



- (i) Use data from **Figure 2** to show that p is inversely proportional to L .

(3)

- (ii) Name the physical property of the gas which must remain constant for p to be inversely proportional to L .

(1)

- (d) Explain how the relationship between p and L shown in **Figure 2** can be predicted using the kinetic theory for an ideal gas.

(4)

(Total 22 marks)

5

- (a) Define the Avogadro constant.

(1)

- (b) (i) Calculate the mean kinetic energy of krypton atoms in a sample of gas at a temperature of 22 °C.

mean kinetic energy _____ J

(1)

- (ii) Calculate the mean-square speed, $(c_{\text{rms}})^2$, of krypton atoms in a sample of gas at a temperature of 22 °C.

State an appropriate unit for your answer.

mass of 1 mole of krypton = 0.084 kg

mean-square speed _____ unit _____

(3)

- (c) A sample of gas consists of a mixture of krypton and argon atoms.
The mass of a krypton atom is greater than that of an argon atom.
State and explain how the mean-square speed of krypton atoms in the gas compares with that of the argon atoms at the same temperature.

(2)

(Total 7 marks)

6

- (a) Outline what is meant by an *ideal gas*.

(2)

- (b) An ideal gas at a temperature of $22\text{ }^{\circ}\text{C}$ is trapped in a metal cylinder of volume 0.20 m^3 at a pressure of $1.6 \times 10^6\text{ Pa}$.

(i) Calculate the number of moles of gas contained in the cylinder.

number of moles _____ mol

(2)

(ii) The gas has a molar mass of $4.3 \times 10^{-2}\text{ kg mol}^{-1}$.

Calculate the density of the gas in the cylinder.

State an appropriate unit for your answer.

density _____ unit _____

(3)

(iii) The cylinder is taken to high altitude where the temperature is $-50\text{ }^{\circ}\text{C}$ and the pressure is $3.6 \times 10^4\text{ Pa}$. A valve on the cylinder is opened to allow gas to escape.

Calculate the mass of gas remaining in the cylinder when it reaches equilibrium with its surroundings.

Give your answer to an appropriate number of significant figures.

mass _____ kg

(3)

(Total 10 marks)

Figure 1

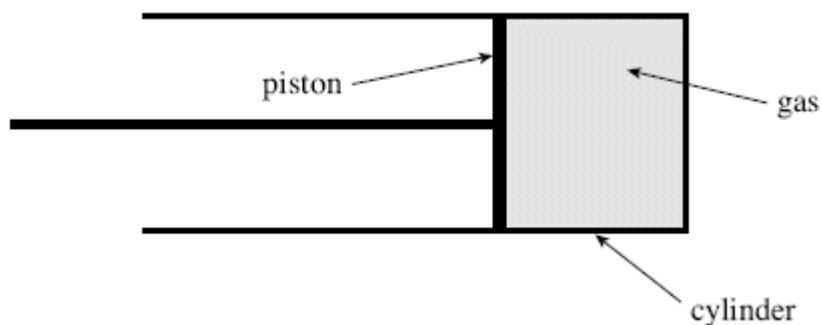
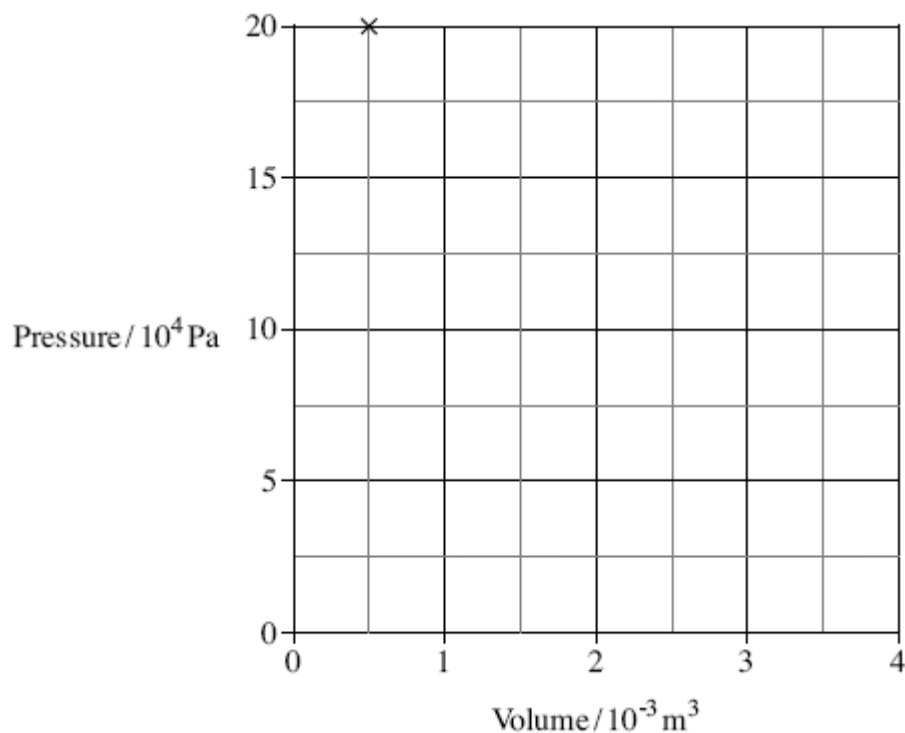


Figure 1 shows a cylinder, fitted with a gas-tight piston, containing an ideal gas at a constant temperature of 290 K. When the pressure, p , in the cylinder is 20×10^4 Pa the volume, V , is $0.5 \times 10^{-3} \text{ m}^3$.

Figure 2 shows this data plotted.

Figure 2



- (a) By plotting two or three additional points draw a graph, on the axes given in **Figure 2**, to show the relationship between pressure and volume as the piston is slowly pulled out. The temperature of the gas remains constant.

- (b) (i) Calculate the number of gas molecules in the cylinder.

answer = _____ molecules

(2)

- (ii) Calculate the total kinetic energy of the gas molecules.

answer = _____ J

(3)

- (c) State **four** assumptions made in the molecular kinetic theory model of an ideal gas.

(i) _____

(ii) _____

(iii) _____

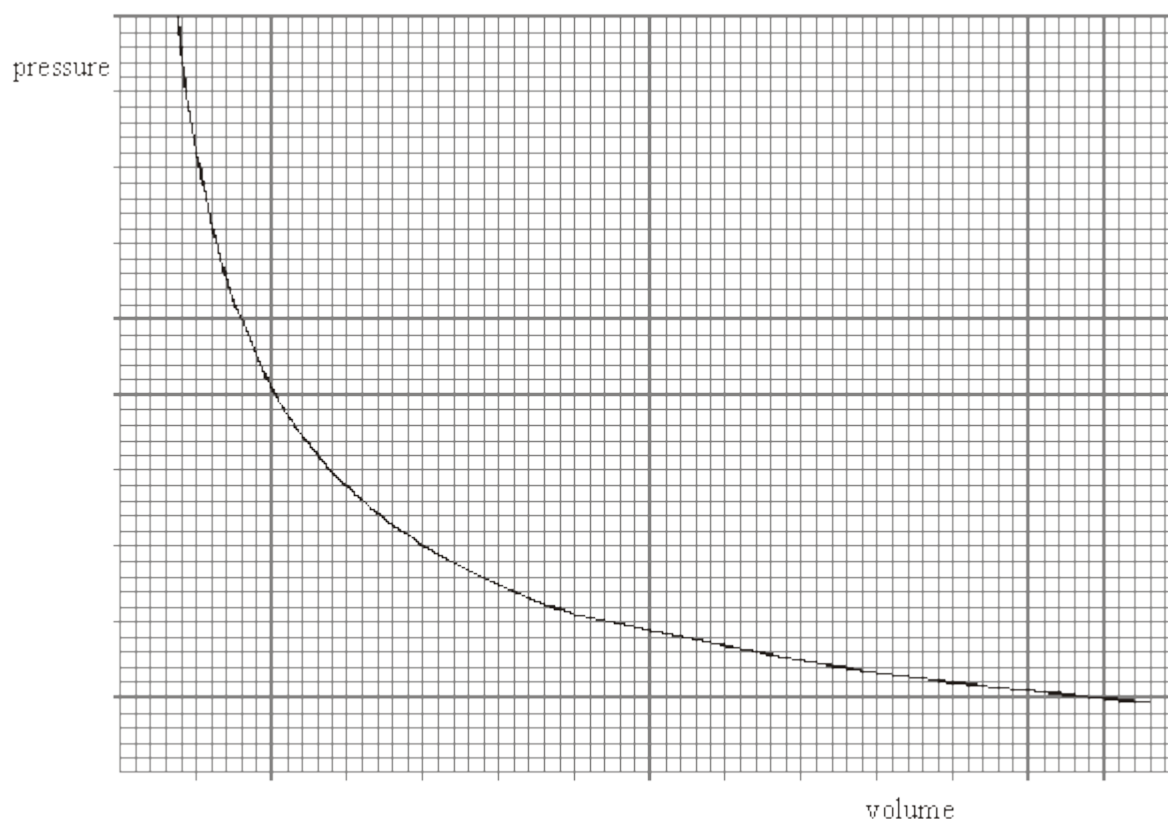
(iv) _____

(4)

(Total 12 marks)

8

The graph shows how the pressure of an ideal gas varies with its volume when the mass and temperature of the gas are constant.



(a) On the same axes, sketch **two** additional curves **A** and **B**, if the following changes are made.

- (i) The same mass of gas at a lower constant temperature (label this **A**).
- (ii) A greater mass of gas at the original constant temperature (label this **B**).

(2)

(b) A cylinder of volume 0.20 m^3 contains an ideal gas at a pressure of 130 kPa and a temperature of 290 K . Calculate

- (i) the amount of gas, in moles, in the cylinder,

- (ii) the average kinetic energy of a molecule of gas in the cylinder,

- (iii) the average kinetic energy of the molecules in the cylinder.

(5)

(Total 7 marks)

9

The pressure inside a bicycle tyre of volume $1.90 \times 10^{-3} \text{ m}^3$ is $3.20 \times 10^5 \text{ Pa}$ when the temperature is 285 K.

- (i) Calculate the number of moles of air in the tyre.

answer = _____ mol

(1)

- (ii) After the bicycle has been ridden the temperature of the air in the tyre is 295 K. Calculate the new pressure in the tyre assuming the volume is unchanged. Give your answer to an appropriate number of significant figures.

answer = _____ Pa

(3)

- (b) Describe **one** way in which the motion of the molecules of air inside the bicycle tyre is similar and **one** way in which it is different at the two temperatures.

similar _____

different _____

(2)

(Total 6 marks)

10

- (a) The air in a room of volume 27.0 m^3 is at a temperature of 22°C and a pressure of 105 kPa .

Calculate

- (i) the temperature, in K, of the air,

- (ii) the number of moles of air in the room,

- (iii) the number of gas molecules in the room.

(5)

- (b) The temperature of an ideal gas in a sealed container falls. State, with a reason, what happens to the

- (i) mean square speed of the gas molecules,

(ii) pressure of the gas.

(4)

(Total 9 marks)

11

(a) A cylinder of fixed volume contains 15 mol of an ideal gas at a pressure of 500 kPa and a temperature of 290 K.

(i) Show that the volume of the cylinder is $7.2 \times 10^{-2} \text{ m}^3$.

(ii) Calculate the average kinetic energy of a gas molecule in the cylinder.

(4)

(b) A quantity of gas is removed from the cylinder and the pressure of the remaining gas falls to 420 kPa. If the temperature of the gas is unchanged, calculate the amount, in mol, of gas remaining in the cylinder.

(2)

- (c) Explain in terms of the kinetic theory why the pressure of the gas in the cylinder falls when gas is removed from the cylinder.

(4)

(Total 10 marks)

12

- (a) Write down **four** assumptions about the properties and behaviour of gas molecules which are used in the kinetic theory to derive an expression for the pressure of an ideal gas.

Assumption 1 _____

Assumption 2 _____

Assumption 3 _____

Assumption 4 _____

(4)

- (b) (i) A cylinder, fitted with a pressure gauge, contains an ideal gas and is stored in a cold room. When the cylinder is moved to a warmer room the pressure of the gas is seen to increase. Explain **in terms of the kinetic theory** why this increase in pressure is expected.

- (ii) After a time, the pressure of the gas stops rising and remains steady at its new value. The air temperature in the warmer room is 27°C . Calculate the mean kinetic energy of a gas molecule in the cylinder.

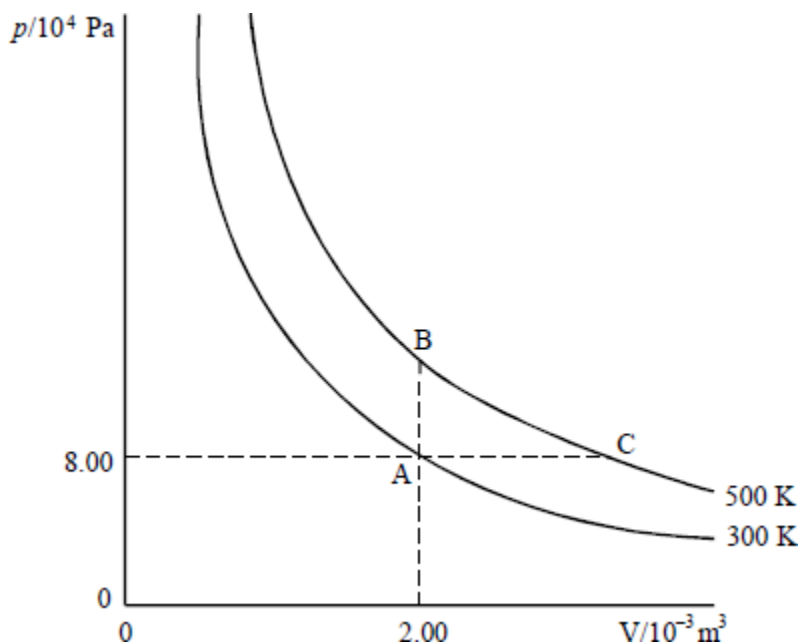
(6)

(Total 10 marks)

13

- (a) The diagram shows curves (not to scale) relating pressure p , and volume, V , for a fixed mass of an ideal monatomic gas at 300K and 500K . The gas is in a container which is closed by a piston which can move with negligible friction.

molar gas constant, R , $= 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$



- (i) Show that the number of moles of gas in the container is 6.4×10^{-2} .

- (ii) Calculate the volume of the gas at point C on the graph.

(3)

- (b) (i) Give an expression for the total kinetic energy of the molecules in one mole of an ideal gas at kelvin temperature T .

- (ii) Calculate the total kinetic energy of the molecules of the gas in the container at point A on the graph.

Explain why this equals the total internal energy for an ideal gas.

(4)

- (c) Defining the terms used, explain how the first law of thermodynamics, $\Delta Q = \Delta U + \Delta W$, applies to the changes on the graph

- (i) at constant volume from A to B,

- (ii) at constant pressure from A to C.

(5)

- (d) Calculate the heat energy absorbed by the gas in the change

- (i) from A to B,

(ii) from A to C

(3)

(Total 15 marks)

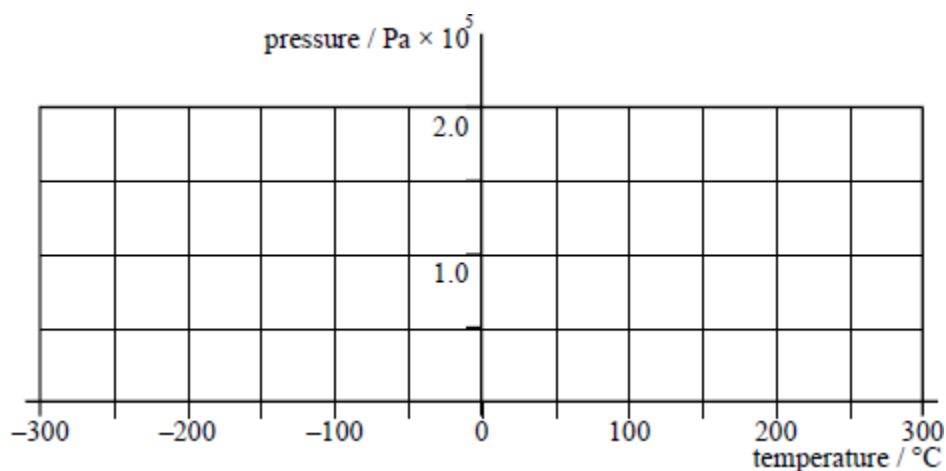
14

The pressure exerted by an ideal gas in a container of volume $1.2 \times 10^{-5} \text{ m}^3$ is $1.5 \times 10^5 \text{ Pa}$ at a temperature of 50°C .

(a) Calculate the number of molecules of gas in the container.

(3)

(b) The pressure of the gas is measured at different temperatures whilst the volume of the container and the mass of the gas remain constant. Draw a graph on the grid to show how the pressure varies with the temperature.



(3)

- (c) The container described in part (a) has a release valve that allows gas to escape when the pressure exceeds 2.0×10^5 Pa. Calculate the number of gas molecules that escape when the temperature of the gas is raised to 300°C .

(3)

(Total 9 marks)

15

- (a) Use the kinetic theory of gases to explain why

- (i) the pressure exerted by an ideal gas increases when it is heated at constant volume.

- (ii) the volume occupied by an ideal gas increases when it is heated at constant pressure.

(4)

- (b) A quantity of 0.25 mol of air enters a diesel engine at a pressure of 1.05×10^5 Pa and a temperature of 27°C . Assume the gas to be ideal.

- (i) Calculate the volume occupied by the gas.

- (ii) When the gas is compressed to one twentieth of its original volume the pressure rises to 7.0×10^6 Pa. Calculate the temperature of the gas immediately after the compression.

(4)

(Total 8 marks)

16

- (a) (i) State what is meant by *thermal equilibrium*.

- (ii) Explain thermal equilibrium by reference to the behaviour of the molecules when a sample of hot gas is mixed with a sample of cooler gas and thermal equilibrium is reached.

(3)

- (b) A sealed container holds a mixture of nitrogen molecules and helium molecules at a temperature of 290 K. The total pressure exerted by the gas on the container is 120 kPa.

molar mass of helium	=	$4.00 \times 10^{-3} \text{ kg mol}^{-1}$
molar gas constant R	=	$8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Avogadro constant N_A	=	$6.02 \times 10^{23} \text{ mol}^{-1}$

- (i) Calculate the root mean square speed of the helium molecules.

- (ii) Calculate the average kinetic energy of a nitrogen molecule.

- (iii) If there are twice as many helium molecules as nitrogen molecules in the container, calculate the pressure exerted on the container by the helium molecules.

(6)

(Total 9 marks)

17

Most cars manufactured in recent years have been fitted with air bags as a safety feature. In a collision the bag inflates automatically to protect the driver as air is released from a compressed air cylinder.

- (a) Explain why the driver would be less seriously injured in a collision if the air bag inflates than he would be if unrestrained.

(5)

- (b) Why is the driver of a car fitted only with seat belts more likely to be injured than if an air bag was fitted? Ignore the different deceleration times and the difference in the materials used.

(2)

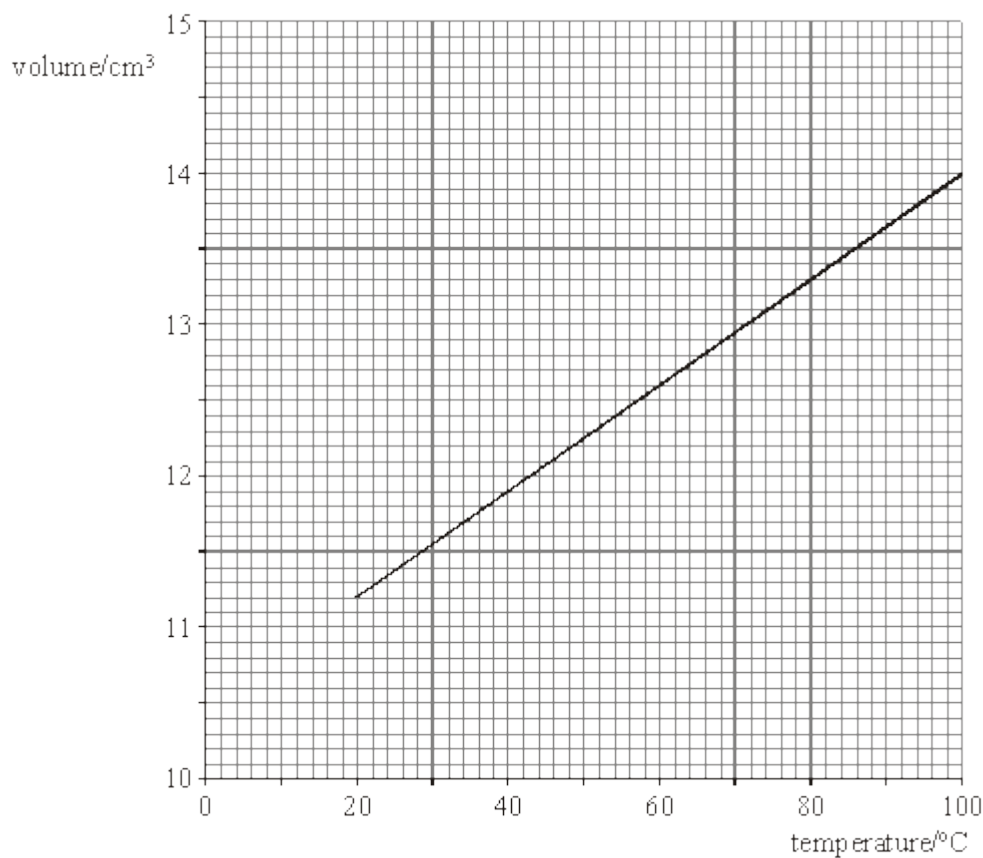
- (c) With reference to pressure, volume and temperature, discuss what happens to the air as the bag inflates.

(3)

(Total 10 marks)

18

The graph in the figure below shows the best fit line for the results of an experiment in which the volume of a fixed mass of gas was measured over a temperature range from 20°C to 100°C. The pressure of the gas remained constant throughout the experiment.



- (a) Use the graph in the figure to calculate a value for the absolute zero of temperature in °C. Show clearly your method of working.

(4)

- (b) Use data from the graph in the figure to calculate the mass of gas used in the experiment. You may assume that the gas behaved like an ideal gas throughout the experiment.

$$\text{gas pressure throughout the experiment} = 1.0 \times 10^5 \text{ Pa}$$

$$\text{molar gas constant} = 8.3 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$\text{molar mass of the gas used} = 0.044 \text{ kg mol}^{-1}$$

(5)

(Total 9 marks)

19

Figure 1 shows a p - V graph that you are to use to illustrate the process of a gas undergoing two changes.

In its initial state, the gas has a pressure of 50 kPa and a volume of 1.5 m^3 ; this is plotted on the graph.

First, the gas undergoes an isothermal change from an initial volume of 1.5 m^3 to 0.85 m^3 followed by a compression at constant pressure to a volume of 0.35 m^3 .

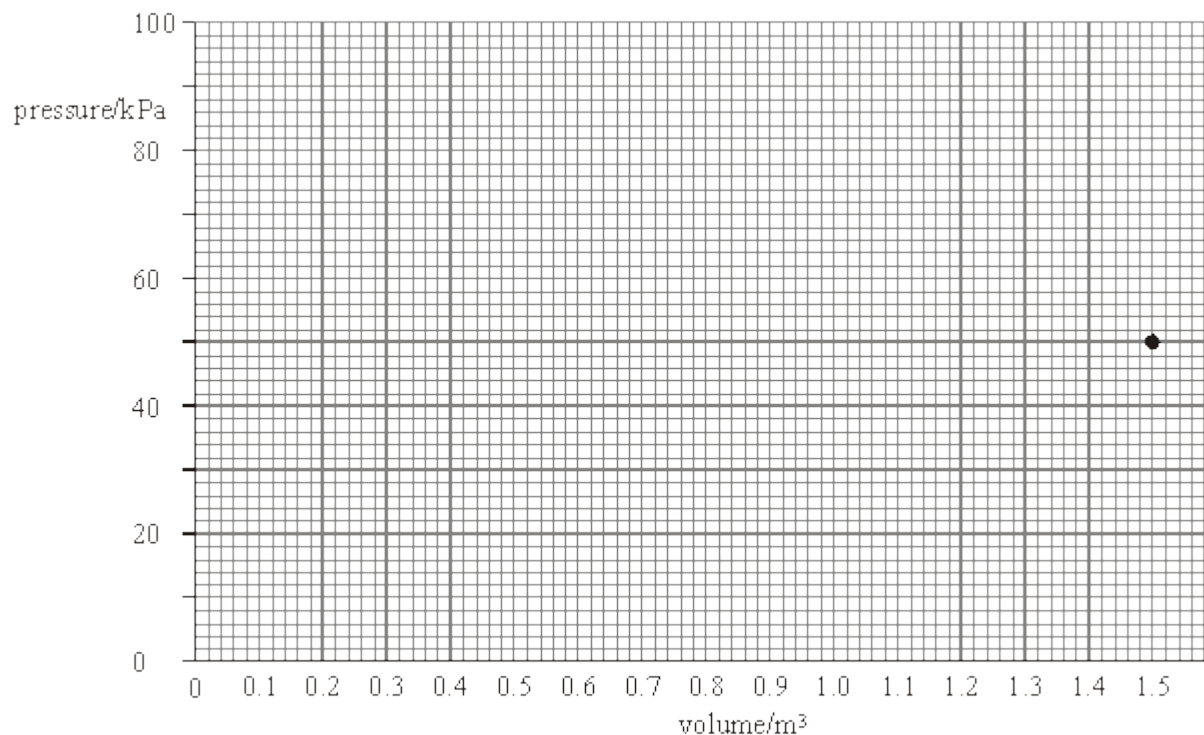


Figure 1

(a) Show that the final pressure of the gas is about 90 kPa.

(2)

(b) Complete the graph in **Figure 1** to show both changes.

(2)

(c) (i) Use your graph to estimate the work done during the whole process.

(3)

(ii) State and explain whether the work in part (c)(i) is done *on* or *by* the gas.

(1)

(Total 8 marks)

Mark schemes

1

- (a) The molecules (continually) move about in random motion✓

Collisions of molecules with each other and with the walls are elastic✓

Time in contact is small compared with time between collisions✓

The molecules move in straight lines between collisions✓

ANY TWO

Allow reference to 'particles interact according to Newtonian mechanics'

2

- (b) Ideas of pressure = F / A and $F = \text{rate of change of momentum}$ ✓

Mean KE / rms speed / mean speed of air molecules increases✓

More collisions with the inside surface of the football each second✓

Allow reference to 'Greater change in momentum for each collision'

3

- (c) Radius = $690 \text{ mm} / 6.28 = 110 \text{ mm}$ or $T = 290 \text{ K}$ ✓ seen

volume of air = $5.55 \times 10^{-3} \text{ m}^3$ ✓

$n \times 29(\text{g}) = 11.4 \text{ (g)}$ ✓ $n = 0.392 \text{ mol}$

Use of $pV = nRT = \frac{0.392 \times 8.31 \times 290}{5.55 \times 10^{-3} \text{ m}^3}$ ✓

$p = 1.70 \times 10^5 \text{ Pa}$ ✓

Conclusion: Appropriate comparison of their value for p with the requirement of the rule, ie whether their pressure above $1 \times 10^5 \text{ Pa}$ falls within the required band✓

Allow ecf for their n V and T ✓

6

[11]

2

C

[1]

3

- (a) 1. fixed mass or fixed number of molecules / moles ✓
2. constant temperature ✓

Allow alternatives to fixed mass such as 'sealed vessel' or 'closed system'.

Not amount of gas as this is ambiguous.

The temperature must not be specific.

(b) (i) $(V_2 = \frac{P_1}{P_2} \times V_1 \times \frac{T_2}{T_1})$

$$V_2 = \frac{1.0 \times 10^5}{4.4 \times 10^5} \times 0.0016 \times \frac{350}{290}$$

or $(V = \frac{nRT}{P})$

$$V = 0.067 \times 8.31 \times 350 / (4.4 \times 10^{-4}) \checkmark$$

$$= 0.00044 \text{ (m}^3\text{)} \checkmark (4.39 \times 10^{-4} \text{ m}^3)$$

1st mark comes from use of valid equation with substitutions.

In the alternative look out for $0.067 = 1/15 = (0.0016 / 0.024)$

And $R = N_A k$

Correct answer gains full marks

If no other answer is seen then 1 sig fig is wrong.

2

(ii) (proportion of a mole of trapped air
= volume of cylinder / volume of mole)
= $0.0016 / 0.024 = 0.067 \text{ (mol)} \checkmark (0.0667)$
or
(use of $n = pV/RT$)
= $1.0 \times 10^5 \times 0.0016 / (8.31 \times 290) = 0.066 \text{ (mol)} \checkmark (0.0664)$
or
= $4.4 \times 10^5 \times 0.00044 / (8.31 \times 350) = 0.067 \text{ (mol)} \checkmark (0.0666)$
Answers range between 0.066 – 0.067 mol depending on the volume carried forward.
(answer alone gains mark)
Working must be shown for a CE
Ans = $V_2 \times 151$

1

(iii) (mass = molar mass $\times$ number of moles)
mass = $0.029 \times 0.0667 \checkmark (0.00193 \text{ kg})$
(density = mass / volume)
density = $0.00193 / 0.0016 = 1.2(1) \text{ kg m}^{-3} \checkmark$
(no continuation errors within this question but allow simple powers of 10 arithmetic errors which will lose one mark)
CE mass = $0.029 \times (b)(ii)$
CE density = $(0.029 \times (b)(ii)) / 0.0016$
or $(18.1 \times (b)(ii))$

2

(c) the (average / mean / mean-square) speed of molecules increases (with absolute temperature) $\checkmark$

as the mean kinetic energy is proportional to the (absolute) temperature

Or

Reference to $KE_{\text{mean}} = 3/2 kT \checkmark$ but mean or rms must feature in the answer somewhere.

2

4

- (a) (i) Use of $V = \pi r^2 L$

$$3.47 \times 10^{-2} \text{ or } 3.5 \times 10^{-2} \text{ (m)}$$

Sub including V and L (condone L=18)

Or rearrangement to make r subject of correct equation

Condone power 10 error on L

1 mark for following answers

$$1.7 \times 10^{-2}, 1.7 \times 10^{-3}, 3.5 \times 10^{-3} \text{ (m)}$$

2

- (ii) Use of $pV = NkT$ or $T = 19 + 273$ or $T = 292$ seen

Allow rearrangement making N subject $N = \frac{pV}{kT}$

Correct use of $pV = NkT$ substitution

$$4.26 \times 10^{21} \text{ seen or } 4.3 \times 10^{21} \text{ seen}$$

Condone sub of 19 for T for 1st mark in either method

$$\text{Or } (N =) \frac{1.01 \times 10^5 \times 1.7 \times 10^{-4}}{1.38 \times 10^{-23} \times 292} \text{ seen with } pV = NkT \text{ seen}$$

Alternative use of $pV = nRT$ and $N = nN_A$ in first and second marks

First mark condone $T = 19$

$$\text{Second mark } pV = nRT \text{ seen with use of and } 7(.08) \times 10^{-3} \times 6(.02) \times 10^{23} \text{ seen}$$

3

- (iii) $(NV=) 1.7 \times 10^{-4} \times 7 \times 10^{-4} \text{ or } 1.19 \times 10^{-7} \text{ seen}$

$$2.76 \times 10^{-29} \text{ to } 3.0 \times 10^{-29} \text{ (m}^3\text{) condone 1 sf here}$$

Penalise where product does not equal 1.19×10^{-7}

2

- (iv) • the volume of molecule(s) is negligible **compared to** volume occupied by gas
- the particles are far apart / large spaces between particles (compared to their diameter)
- **Therefore** Time during collisions is negligible compared to time between collision
- **Therefore** intermolecular forces are negligible
- Allow volume of one molecule is negligible compared to total volume*

Max 3

- (b) Use of $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ sub or rearrangement
 Condone c_{rms} as subject for 1 mark
 Condone power 10 error
 Condone $T = 19$ in 1st MP
 Correct sub with $\langle c^2 \rangle$ as subject including correct power 10
 2.57×10^5 or 2.6×10^5 (on answer line)
 $m^2 s^{-2}$

Alternatively:

use of $pV = \frac{1}{3} Nm \langle c^2 \rangle$ sub or rearrangement

Condone c_{rms} as subject for 1 mark

Condone power 10 error

Condone $T = 19$ in 1st MP

Correct sub with $\langle c^2 \rangle$ as subject including correct power 10

$2.7(4) \times 10^5$ (from $N = 4 \times 10^{21}$) (on answer line)

2.57×10^5 for $N = 4.26 \times 10^{21}$

$2.5(48) \times 10^5$ for $N = 4.3 \times 10^{21}$

$m^2 s^{-2}$

condone alternative units where correct:

$Pa m^3 kg^{-1}$

$J kg^{-1}$

4

- (c) (i) $p_1 L_1 = k_1$ and $p_2 L_2 = k_2$

(consistent power 10)

i.e. 2 sets of **correct data**

seen in sub

allow incomplete sub with 2

similar k (18×10^3) values seen

$$p_1 L_1 = k_1, p_2 L_2 = k_2 \text{ and } p_3 L_3 = k_3$$

(consistent power 10)

i.e. 3 sets of **correct data**

seen in sub

Comparison of k values followed by conclusion

Presents a factorial of L leading to an inverse of the factorial change in P (correct data)

*Repeats this process for **second** data set for same factorial change (correct data)*

States the relationship seen and **states** the conclusion

3

(ii) Temperature or internal energy

Allow mass / number of particles / mean square speed (of molecules)

1

(d) L decreases then volume decreases (therefore more particles in any given volume) / $V = \pi r^2 L$ / V is (directly) proportional to L

Decreased volume Increases number of collisions (with walls every second)

Decreased volume causes Rate of change of momentum to increase

Increased rate of change of momentum causes force (exerted on walls) to increase (causing an increase in pressure)

Allow converse argument but must be consistent

$$p = \frac{1}{3} \frac{Nm \overline{c^2}}{\pi r^2 L} \text{ or equivalent}$$

*must be correct equation with V in terms of L
with p as subject*

4

[22]

5

(a) the number of atoms in 12g of carbon-12

or the number of particles / atoms / molecules in one mole of substance ✓

not – N_A quoted as a number

1

(b) (i) mean kinetic energy ($= \frac{3}{2} kT$) $= \frac{3}{2} \times 1.38 \times 10^{-23} \times (273 + 22)$
 $= 6.1 \times 10^{-21}$ (J) ✓

6×10^{-21} J is not given mark

1

(ii) mass of krypton atom

$$= 0.084 / 6.02 \times 10^{+23} \checkmark$$

$$(\text{ } = 1.4 \times 10^{-25} \text{ kg})$$

$$\overline{c^2} (= 2 \times \text{mean kinetic energy} / \text{mass})$$

$$= 2 \times 6.1 \times 10^{-21} / 1.4 \times 10^{-25})$$

$$= 8.7 - 8.8 \times 10^4 \checkmark$$

$$\text{m}^2 \text{ s}^{-2} \text{ or } \text{J kg}^{-1} \checkmark$$

1st mark is for the substitution which will normally be seen within a larger calculation.

allow CE from (i)

working must be shown for a CE otherwise full marks can be given for correct answer only

no calculation marks if mass has a physics error i.e. no division by N_A note for CE

answer = (i) $\times 1.43 \times 10^{25}$

3

- (c) (at the same temperature) the mean kinetic energy is the same
or

gases have equal $\frac{1}{2} m c_{rms}^2$

or

mass is inversely proportional to mean square speed / $m \propto 1 / \overline{c^2}$ ✓

$\overline{c^2}$ or mean square speed of krypton is less ✓

1st mark requires the word mean / average or equivalent in an algebraic term

2nd mark 'It' will be taken to mean krypton. So, 'It is less' can gain a mark

allow 'heavier' to mean more massive'

allow vague statements like speed is less for 2nd mark but not in the first mark

2

[7]

6

- (a) molecules have negligible volume
collisions are elastic
the gas cannot be liquified
there are no interactions between molecules (except during collisions)
the gas obeys the (ideal) gas law / obeys Boyles law etc.
at all temperatures/pressures
any two lines ✓ ✓

a gas laws may be given as a formula

2

- (b) (i) $n (= PV / RT) = 1.60 \times 10^6 \times 0.200 / (8.31 \times (273 + 22))$ ✓
= 130 or 131 mol ✓ (130.5 mol)

2

- (ii) mass = $130.5 \times 0.043 = 5.6$ (kg) ✓
(5.61kg)

allow ecf from bi

density (= mass / volume) = $5.61 / 0.200 = 28$ ✓ (28.1 kg m⁻³)
kg m⁻³ ✓

a numerical answer without working can gain the first two marks

3

(iii) $(V_2 = P_1 V_1 T_2 / P_2 T_1)$

$$V_2 = 1.6 \times 10^6 \times .200 \times (273 - 50) / 3.6 \times 10^4 \times (273 + 22) \text{ or } 6.7(2) (m^3) \checkmark$$

allow ecf from bii

[reminder must see bii]

look out for

$$\text{mass remaining} = 5.61 \times 0.20 / 6.72 = 0.17 \text{ (kg)} \checkmark (0.167 \text{ kg})$$

or

$$n = (PV / RT = 3.6 \times 10^4 \times 0.200 / (8.31 \times (273 - 50))) = 3.88(5) \text{ (mol)} \checkmark$$

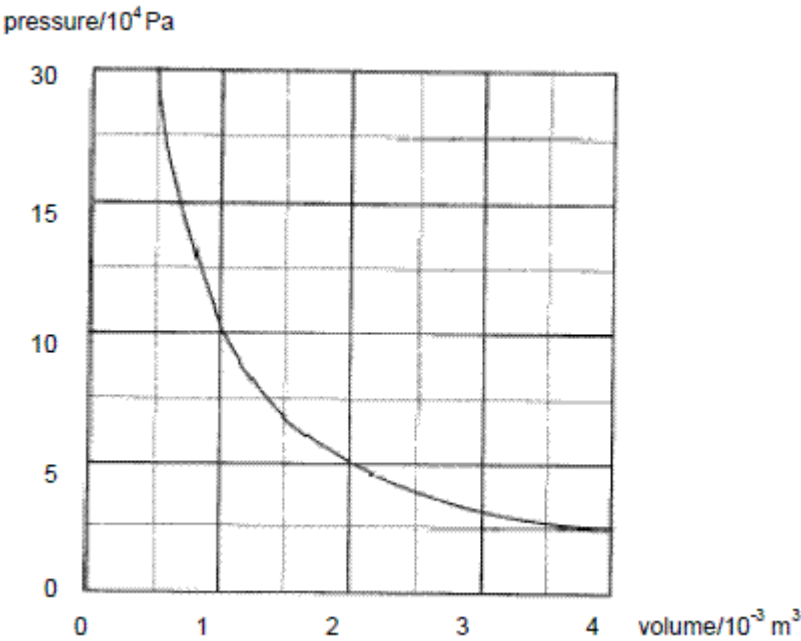
$$\text{mass remaining} = 3.885 \times 4.3 \times 10^{-2} = 0.17 \text{ (kg)} \checkmark$$

2 sig figs $\checkmark$

any 2 sf answer gets the mark

7

(a)



3

curve with decreasing negative gradient that passes through the given point which does not touch the x axis **(1)**

designated points	
pressure/ 10^4 Pa	volume/ 10^{-3} m ³
10	1.0
5.0	2.0
4.0	2.5
2.5	4.0

2 of the designated points **(1)(1)** (one mark each)

(b) (i) $N = PV/kT = 5 \times 10^4 \times 2 \times 10^{-3} / 1.38 \times 10^{-23} \times 290$ **(1)**

[or alternative use of $PV = nRT$
 $5 \times 10^4 \times 2.0 \times 10^{-3} / 8.31 \times 290 = 0.0415$ moles]
 $= 2.50 \times 10^{22}$ molecules **(1)**

2

(ii) (mean) kinetic energy of a molecule

$$= \frac{3}{2} kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290 \quad \textbf{(1)} (= 6.00 \times 10^{-21} \text{ J})$$

(total kinetic energy = mean kinetic energy $\times N$)

$$= 6.00 \times 10^{-21} \times 2.50 \times 10^{22} \quad \textbf{(1)}$$

$$= 150 \text{ (J)} \quad \textbf{(1)}$$

3

(c) all molecules/atoms are identical

molecules/atoms are in random motion

Newtonian mechanics apply

gas contains a large number of molecules

the volume of gas molecules is negligible (compared to the volume occupied by the gas) or reference to point masses

no force act between molecules except during collisions or the speed/velocity is constant between collisions or motion is in a straight line between collisions

collisions are elastic or **kinetic** energy is conserved

and of negligible duration

any 4 (1)(1)(1)(1)

max 4

[12]

8

(a) (i) curve A below original, curve B above original **(1)**

(ii) both curves correct shape **(1)**

2

(b) (i) (use of $pV = nRT$ gives) $130 \times 10^3 \times 0.20 = n \times 8.31 \times 290$ **(1)**

$n = 11 \text{ (mol)} \quad \textbf{(1)} \text{ (10.8 mol)}$

(ii) (use of $E_k = \frac{3}{2} kT$ gives) $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$ **(1)**

$= 6.0 \times 10^{-21} \text{ J} \quad \textbf{(1)}$

(iii) (no. of molecules) $N = 6.02 \times 10^{23} \times 10.8 (= 6.5 \times 10^{24})$

total k.e. $= 6.5 \times 10^{24} \times 6.0 \times 10^{-21} = 3.9 \times 10^4 \text{ J} \quad \textbf{(1)}$

(allow C.E. for value of n and E_k from (i) and (ii))

(use of $n = 11 \text{ (mol)}$ gives total k.e. $= 3.9 \text{ (7)} \times 10^4 \text{ J}$)

5

[7]

9

(a) (i) $n = PV/RT = 3.2 \times 10^5 \times 1.9 \times 10^{-3} / 8.31 \times 285$

$n = 0.26 \text{ mol}$ ✓ (0.257 mol)

1

(ii) $P_2 = \frac{T_2}{T_1} \times P_1 = \frac{295}{285} \times 3.20 \times 10^5$ ✓

$3.31 \times 10^5 \text{ Pa}$ ✓ (allow $3.30\text{-}3.35 \times 10^5 \text{ Pa}$)

3 sig figs ✓ sig fig mark stands alone even with incorrect answer

3

(b) similar -(rapid) **random** motion

- range of speeds

different - **mean** kinetic energy

- root **mean** square speed

- **frequency** of collisions

2

[6]

10

(a) (i) $T (=273 + 22) = 295 \text{ (K)}$ **(1)**

(ii) $pV = nRT$ **(1)**

$105 \times 10^3 \times 27 = n \times 8.31 \times 295$ **(1)**

$n = 1160 \text{ (moles)}$ **(1)** (1156 moles)

(allow C.E. for T (in K) from (i))

(iii) $N = 1156 \times 6.02 \times 10^{23} = 7.0 \times 10^{26}$ **(1)** (6.96×10^{26})

5

(b) (i) decreases **(1)**

because temperature depends on mean square speed (or $\overline{c^2}$)

[or depends on mean E_k] **(1)**

- (ii) decreases **(1)**
 as number of collisions (per second) falls **(1)**
 rate of change of momentum decreases **(1)**

[or if using $pV = nRT$

decreases **(1)**

as V constant **(1)**

as n constant **(1)**]

[or if using $p = \frac{1}{3}\rho \overline{c^2}$

decrease **(1)**

as ρ is constant **(1)**

as $\overline{c^2}$ is constant **(1)**]

max 4

[9]

11

(a) (i) $pV = nRT$ **(1)**
 $V = \frac{15 \times 8.31 \times 290}{500 \times 10^3}$ **(1)** (gives $V = 7.2 \times 10^{-2} \text{m}^3$)

(ii) (use of $E_k = \frac{3}{2} kT$ gives) $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$ **(1)**

$= 6.0 \times 10^{-21} \text{ (J)}$ **(1)**

4

(b) (use of $pV = nRT$ gives) $n = \frac{420 \times 10^3 \times 7.2 \times 10^{-2}}{8.31 \times 290}$ **(1)**

[or use $p \propto n$]

$n = 13 \text{ moles}$ **(1)** (12.5 moles)

2

- (c) pressure is due to molecular bombardment [or moving molecules] **(1)**
 when gas is removed there are fewer molecules in the cylinder
 [or density decreases] **(1)**

(rate of) bombardment decreases **(1)**
 molecules exert forces on wall **(1)**

$\overline{c^2}$ is constant **(1)**

[or $pV = \frac{1}{3} Nm (c^2)$ **(1)**

V and m constant **(1)**

(c^2) constant since T constant **(1)**

$p \propto N$ **(1)**

[or $p = \frac{1}{3} \rho (c^2)$ **(1)**

explanation of ρ decreasing **(1)**

(c^2) constant since T constant **(1)**

$p (c^2) \rho$ **(1)**

max 4

[10]

12

- (a) number of molecules in a gas is very large
 duration of collision much less than time between collisions
 total volume of molecules small compared with gas volume
 molecules are in random motion
 collisions are (perfectly) elastic
 there are no forces between molecules (any four) **(4)**

(any 4)

- (b) (i) heat (energy) transferred to gas from warmer air outside
 mean kinetic energy of gas molecules increases
 or molecules move faster
 momentum of molecules increases
 more collisions per second
 each collision (with container walls) transfers more momentum
 force (per unit area) on container wall increases (any four) **(4)**

The Quality of Written Communication marks were awarded primarily for the quality of answers to this part.

(ii) $T = 273 + 27 = 300\text{K}$ **(1)**

mean kinetic energy = $\frac{3}{2}kT$

$= 1.5 \times 1.38 \times 10^{-23} \times 300 = 6.2 \times 10^{-21} \text{ J}$ **(1)**

(allow e.c.f. for incorrect T)

(6)

[10]

13

- (a) (i) correct p and V from graph **(1)**

$$n = \frac{8.0 \times 10^4 \times 2.00 \times 10^{-3}}{8.31 \times 300} \text{ **(1)** } (= 0.0064 \text{ mol})$$

(ii) $V_2 = V_1 \frac{T_2}{T_1} = 3.3 \times 10^{-3} \text{ m}^3$ **(1)**

(3)

(b) (i) $\frac{3}{2} RT$ or $\frac{3}{2} N_A kT$ **(1)**

(ii) total kinetic energy $\left(= \frac{3}{2} nRT \right) = 1.5 \times 8.3 \times 0.064 \times 300$ **(1)** $= 239 \text{ J}$ **(1)**

molecules have no potential energy **(1)**

no attractive forces [or elastic collisions occur] **(1)**

(max 4)

- (c) ΔQ = heat entering (or leaving) gas

ΔU = change (or increase) in internal energy

ΔW = work done

[(1) (1)] for three definitions, deduct one for each incorrect or missing]

- (i) $\Delta Q = \Delta U$ **(1)**
temperature rises but no work done **(1)**

- (ii) $\Delta Q = \Delta U + \Delta W$ **(1)**
temperature rises and work done in expanding **(1)**

(max 5)

(d) (i) $\Delta U = \frac{3}{2} nR(500 - 300) = 159 \text{ J}$ **(1)** $(= \Delta Q)$

$$(ii) \quad p\Delta V = 8.0 \times 10^4 \times (3.3 - 2.0) \times 10^{-3} = 104 \text{ J (1)}$$

$$\therefore \Delta Q = \Delta U + p\Delta V = 263 \text{ J (1)}$$

(3)

[15]

14

$$(a) \quad n \left(= \frac{pV}{RT} \right) = \frac{1.5 \times 10^5 \times 1.2 \times 10^{-5}}{8.31 \times 323} \text{ (1)} = (6.71 \times 10^{-4} \text{ mol})$$

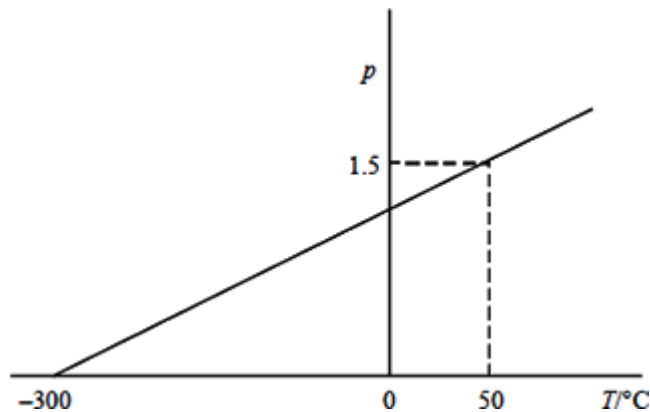
$$\text{number of molecules} = nN_A \text{ (1)} = 6.71 \times 10^{-4} \times 6.02 \times 10^{23}$$

$$= 4.04 \times 10^{20} \text{ (1)}$$

[or equivalent solution using $pV = NkT$]

(3)

(b)



straight line with positive gradient (1)

through (50, 1.5) (1)

crosses temperature axis between -250 and -300°C (1)

(3)

(c) number of moles left in container after valve opens

$$n \left(= \frac{pV}{RT} \right) = \frac{2.0 \times 10^5 \times 1.2 \times 10^{-5}}{8.31 \times 573} \text{ (1)} (= 5.04 \times 10^{-4} \text{ mol})$$

$$\therefore \text{number of molecules left in container} = 5.04 \times 10^{-4} \times 6.02 \times 10^{23}$$

$$= 3.03 \times 10^{20} \text{ (1)}$$

$$\therefore \text{number of molecules that escape} = 4.04 \times 10^{20} - 3.03 \times 10^{20}$$

$$= 1.01 \times 10^{20} \text{ (1)}$$

[alternative (c)]

$$\therefore \text{number of moles that escape} (= 6.71 \times 10^{-4} - 5.04 \times 10^{-4})$$

$$= 1.67 \times 10^{-4}$$

$$\therefore \text{number of molecules that escape} = 1.67 \times 10^{-4} \times N_A$$

$$= 1.01 \times 10^{20} \text{ (1)}$$

(3)

[9]

15

- (a) (i) more collisions (with wall) per second **(1)**
 and more momentum change per collision **(1)**
 greater force because more momentum change per second (greater pressure) **(1)**
- (ii) (same pressure) faster molecules so more momentum change per collision **(1)**
 greater volume, fewer collisions per second [or greater volume
 to maintain same pressure] **(1)**

max 4

(b) (i) $V = \left(\frac{nRT}{p} \right) = \frac{0.250 \times 8.31 \times 300}{1.05 \times 10^5} \text{ (1)} = 5.94 \times 10^{-3} \text{ m}^3 \text{ (1)}$

(ii) $T_2 = \left(\frac{T_1 V_2 P_2}{p_1 V_1} \right) = \frac{300 \times 7.0 \times 10^6}{1.05 \times 10^5 \times 20} \left[\text{or } T_2 = \left(\frac{p_2 V_2}{nR} \right) = \frac{7.0 \times 10^6 \times 5.94 \times 10^{-3}}{8.31 \times 0.25 \times 20} \right] \text{ (1)}$
 $= 1000 \text{ K (727 } ^\circ\text{C) (1)}$

4

[8]**16**

- (a) (i) no net flow of (thermal) energy (between two or more bodies) **(1)**
 bodies at same temperature **(1)**
- (ii) (kinetic) energy is exchanged in molecular collisions **(1)**
 until average kinetic energy of all molecules is the same **(1)**

max 3

$$(b) \quad (i) \quad c_{r.m.s.} \left(= \sqrt{\frac{3RT}{M}} \right) = \sqrt{\frac{3 \times 8.31 \times 290}{4.00 \times 10^{-3}}} \quad (1)$$

$$= 1340 \text{ m s}^{-1} \quad (1)$$

(ii) average k.e. of nitrogen molecules = average k.e. of helium molecules **(1)**

$$= \frac{1}{2} \times \frac{4.00 \times 10^{-3}}{6.02 \times 10^{23}} (1340)^2 = 5.97 \times 10^{-21} \text{ J} \quad (1)$$

alternative schemes for (ii):

$$\text{average k.e.} = \frac{3}{2} kT \quad (1)$$

$$= \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$$

$$= 6.00 \times 10^{-21} \text{ J} \quad (1)$$

or

$$\text{average k.e.} = \frac{3}{2} \frac{RT}{N_A} \quad (1)$$

$$= \frac{3}{2} \times \frac{8.31 \times 290}{6.02 \times 10^{23}}$$

$$= 6.00 \times 10^{-21} \text{ J} \quad (1)$$

(iii) use of $p = \frac{nkT}{V}$ or equivalent [or, at same temperature, $p \propto \text{no. of molecules}$] **(1)**

$$p_{\text{He}} = \frac{2}{3} \times 120 = 80 \text{ kPa} \quad (1)$$

6

[9]

17

(a) moving driver has momentum **(1)**

in sudden impact momentum must be lost in v. short time **(1)**

$$F = \Delta(mv) / \Delta t \text{ (or } F = ma) \quad (1)$$

air bag increases stopping contact time **(1)**

hence reduces force (or reduces force by decreasing the deceleration) **(1)**

(max 5)

(b) seat belt applies force to smaller area than air bag **(1)**

causing greater pressure on parts of body **(1)**

(2)

- (c) air initially at v. high pressure occupies small volume **(1)**
 on expansion volume increases and pressure decreases **(1)**
 temperature of gas decreases as it expands **(1)**
 pressure caused by momentum change in molecular collisions **(1)**

(max 3)

[10]

18

- (a) $m = \text{gradient} = 0.035 \pm 0.001 \text{ (cm}^2 \text{ } ^\circ\text{C}^{-1}\text{)}$

B1

$$c = \text{intercept} = 10.5 \pm 0.1 \text{ (cm}^2\text{)}$$

B1

$$\text{absolute zero} = -c/m$$

C1

$$= -300 \pm 10 \text{ } ^\circ\text{C} \text{ some relevant working must be seen}$$

A1

4

- or a meaningful attempt to use similar triangles

M1

an accurate value for the base found

C1

adjustment to the base (if appropriate)

C1

$$\text{answer} = -300 \pm 10 \text{ } ^\circ\text{C}$$

A1

4

or relevant use of $V_1/T_1 = V_2/T_2$

M1

valid introduction of **unknown** temperature

A1

consistent solution of the equation

C1

answer = $-300 \pm 10^\circ\text{C}$

C1

4

(b) statement of or use of $pV = nRT$

C1

accurate reading from the line

C1

Celsius converted to Kelvin (+273 or + answer to part (a))

C1

$n = 4.52 \times 10^{-4}$ or 4.11×10^{-4} or 4.2×10^{-4} ($\Delta V/\Delta T$) (mol)

A1

$m = n \times 0.044$ ($m = 4.52 \times 0.044 = 2.0 \times 10^{-5}$ kg)

B1

5

[9]

19

(a) $pV = \text{constant}$ seen

C1

$p = 88$ kPa

A1

2

(b) completes correct shape curve to (0.85,88 000 **or** 90000),

B1

then horizontal to 0.35 m³

B1

2

(c) attempts to measure area [graph evidence or words]

C1

correct use of graph scale

C1

answer in range (80 – 91) Kj

A1

3

(d) done **on** gas because it is compressed

B1

1

[8]