

1

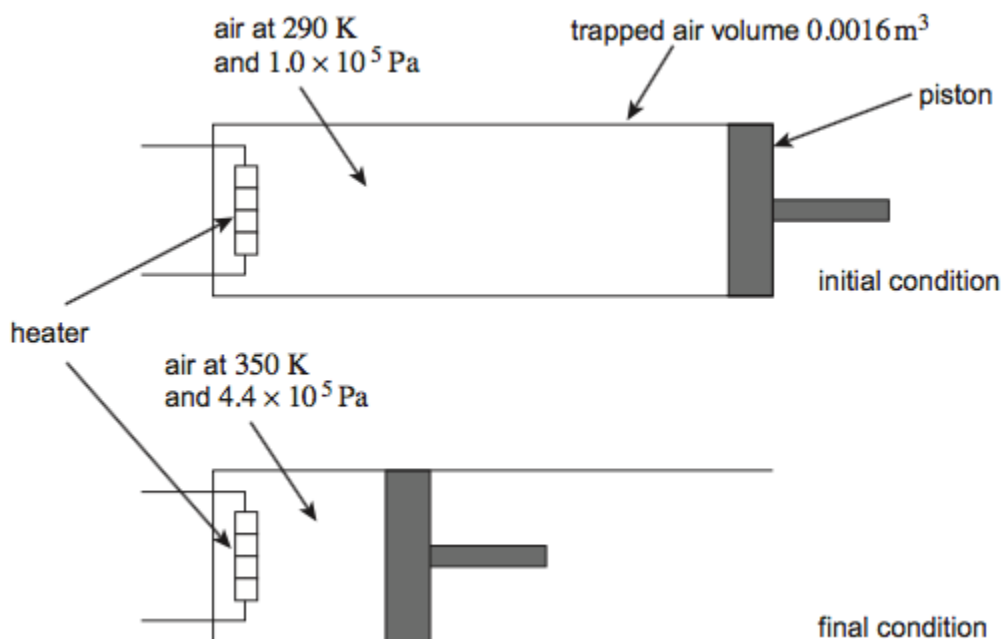
- (a) 'The pressure of an ideal gas is inversely proportional to its volume', is an incomplete statement of Boyle's law.

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)

2

- (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)

3

- (a) The concept of an absolute zero of temperature may be explained by reference to the behaviour of a gas.

Discuss **one** experiment that can be performed using a gas which would enable you to explain absolute zero and determine its value.

It is not necessary to give full details of the apparatus. Your answer should:

- include the quantities that are kept constant
- identify the measurements to be taken
- explain how the results may be used to find absolute zero
- justify why the value obtained is absolute zero.

The quality of your written communication will be assessed in your answer.

(6)

- (b) (i) State **two** assumptions about the **movement** of molecules that are used when deriving the equation of state, $pV = \frac{1}{3} N m (c_{\text{rms}})^2$ for an ideal gas.

1. _____

2. _____

(2)

- (ii) Three molecules move at the speeds shown in the table below.

molecule	speed / m s ⁻¹
1	2000
2	3000
3	7000

Calculate their mean square speed.

mean square speed _____ m² s⁻²

(1)

- (c) The average molecular kinetic energy of an ideal gas is 6.6×10^{-21} J.
Calculate the temperature of the gas.

temperature _____ K

(2)

(Total 11 marks)

4

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)

5

- (a) (i) One of the assumptions of the kinetic theory of gases is that molecules make *elastic collisions*. State what is meant by an elastic collision.

- (ii) State **two** more assumptions that are made in the kinetic theory of gases.

(3)

(b) One mole of hydrogen at a temperature of 420 K is mixed with one mole of oxygen at 320 K. After a short period of time the mixture is in *thermal equilibrium*.

(i) Explain what happens as the two gases approach and then reach thermal equilibrium.

(ii) Calculate the average kinetic energy of the hydrogen molecules before they are mixed with the oxygen molecules.

(4)

(Total 7 marks)

6

Figure 1

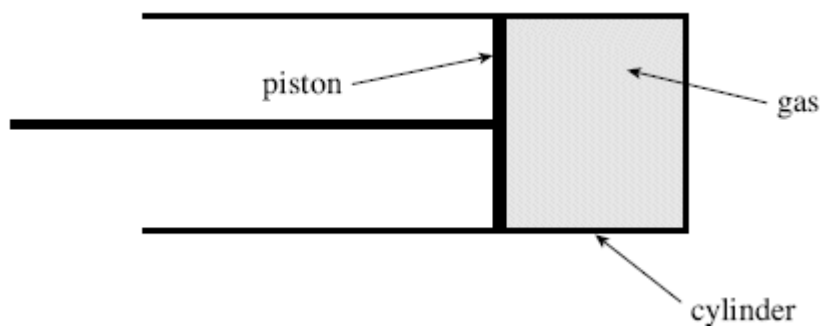
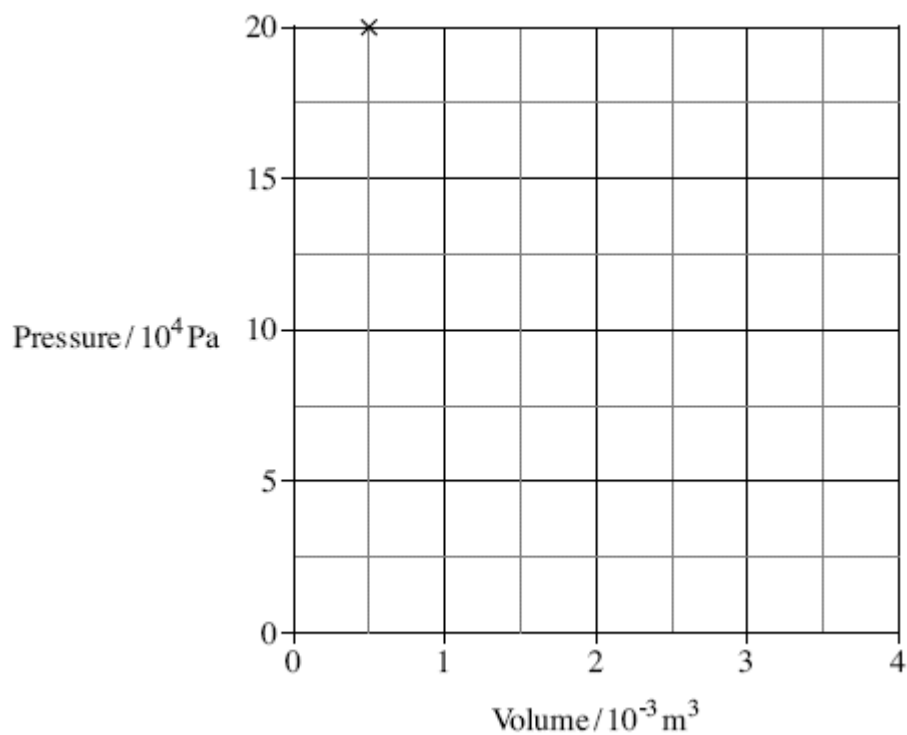


Figure 1 shows a cylinder, fitted with a gas-tight piston, containing an ideal gas at a constant temperature of 290 K. When the pressure, p , in the cylinder is 20×10^4 Pa the volume, V , is $0.5 \times 10^{-3} \text{ m}^3$.

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.

(3)

- (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)

7

- (a) (i) Write down the equation of state for n moles of an ideal gas.

- (ii) The molecular kinetic theory leads to the derivation of the equation

$$pV = \frac{1}{3} Nm \overline{c^2},$$

where the symbols have their usual meaning.

State **three** assumptions that are made in this derivation.

(4)

- (b) Calculate the average kinetic energy of a gas molecule of an ideal gas at a temperature of 20 °C.

(3)

- (c) Two different gases at the same temperature have molecules with different mean square speeds.
Explain why this is possible.

(2)

(Total 9 marks)

8

- (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)

9

(a) The molecular theory model of an ideal gas leads to the derivation of the equation

$$pV = \frac{1}{3} N m \overline{c^2}.$$

Explain what each symbol in the equation represents.

p _____

V _____

N _____

m _____

$\overline{c^2}$ _____

(4)

(b) One assumption used in the derivation of the equation stated in part (a) is that molecules are in state of *random motion*.

(i) Explain what is meant by random motion.

(ii) State **two** more assumptions used in this derivation.

(3)

(c) Describe how the motion of gas molecules can be used to explain the pressure exerted by a gas on the walls of its container.

(4)

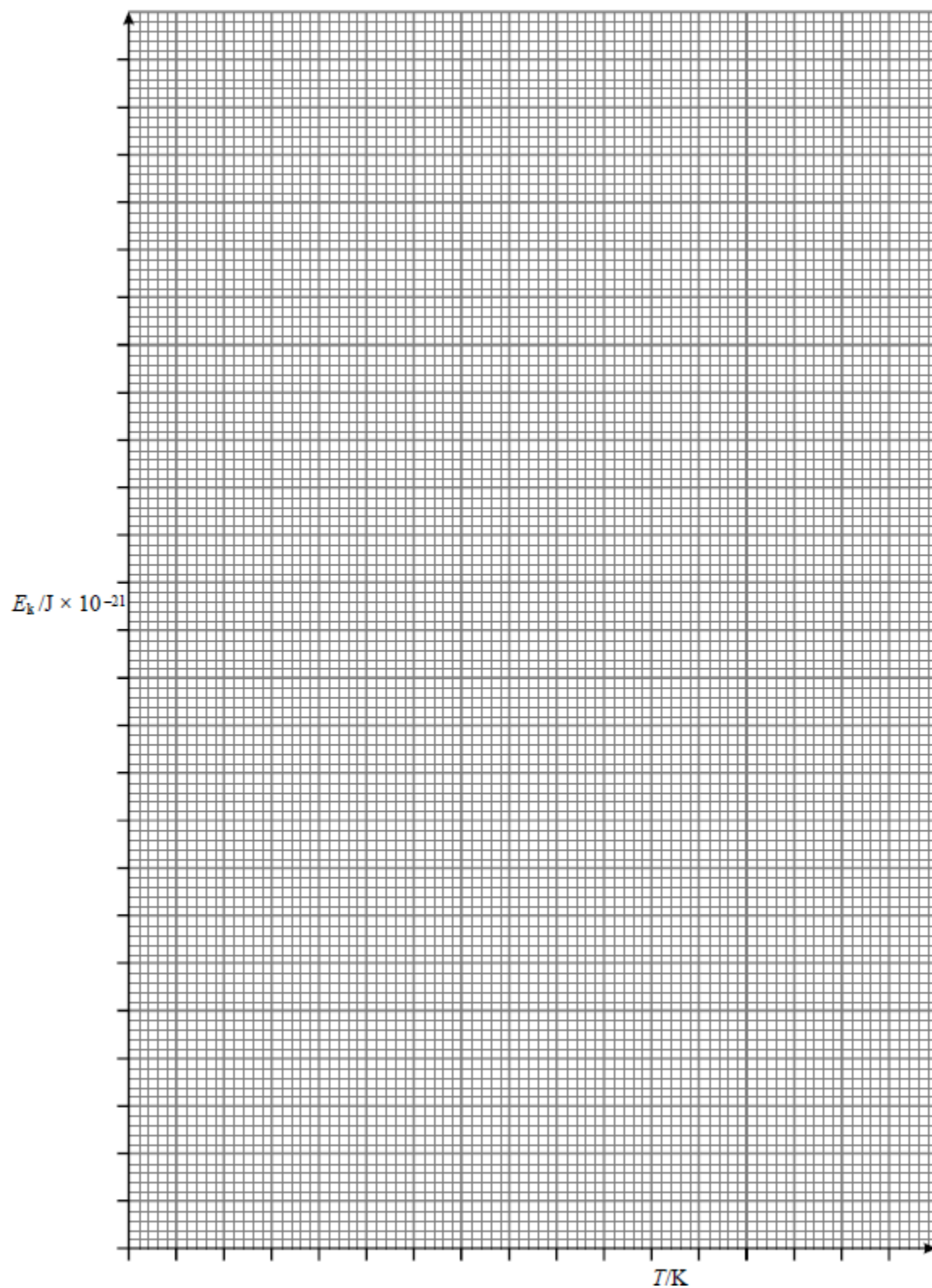
(Total 11 marks)

10

The table gives the average kinetic energy of gas molecules at certain temperatures.

$E_k/\text{J} \times 10^{-21}$	6.21	6.62	7.04	7.45	7.87	8.28
T/K	300	320	340	360	380	400

- (a) On the grid provided below plot a graph of E_k against T .



- (i) Use your graph to determine the average kinetic energy of gas molecules at 350K.

- (ii) Determine the gradient of your graph and hence calculate a value for the Boltzmann constant. Show all your working.

(8)

- (b) One of the assumptions of the kinetic theory is that collisions of gas molecules are elastic.

- (i) State what is meant by an elastic collision.

- (ii) State another assumption of the kinetic theory.

- (iii) Explain how the data in the table leads to the concept of absolute zero.

(4)

(Total 12 marks)

11

- (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)

12

- (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)

13

Helium is a monatomic gas for which all the internal energy of the molecules may be considered to be translational kinetic energy.

$$\text{molar mass of helium} = 4.0 \times 10^{-3} \text{ kg}$$

$$\text{the Boltzmann constant} = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

$$\text{the Avogadro constant} = 6.02 \times 10^{23} \text{ mol}^{-1}$$

- (a) Calculate the kinetic energy of a tennis ball of mass 60 g travelling at 50 m s^{-1} .

(1)

- (b) Calculate the internal energy of 1.0 g of helium gas at a temperature of 48K.

(3)

- (c) At what temperature would the internal energy of 1.0 g of helium gas be equal to the kinetic energy of the ball in part (a).

(1)

(Total 5 marks)

14

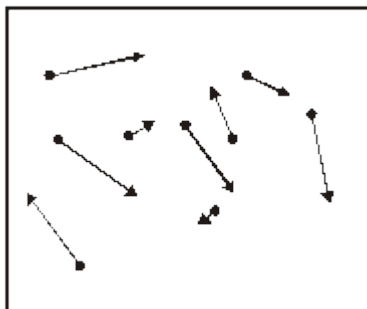
Which one of the following is **not** an assumption about the properties of particles in the simple kinetic theory?

- A $\langle c^2 \rangle$ is the average speed of the particles
- B The forces between the particles are negligible except when particles collide
- C The time spent by particles in collision is negligible compared with the time spent between collisions
- D The volume of the particles is negligible compared to the volume of the container

(Total 1 mark)

15

The diagram below shows a number of smoke particles suspended in air. The arrows indicate the directions in which the particles are moving at a particular time.



- (a) (i) Explain why the smoke particles are observed to move.

(1)

- (ii) Smoke particles are observed to move in a random way. State **two** conclusions about air molecules and their motion resulting from this observation.

(2)

- (b) A sample of air has a density of 1.24 kg m^{-3} at a pressure of $1.01 \times 10^5 \text{ Pa}$ and a temperature of 300 K .

the Boltzmann constant = $1.38 \times 10^{-23} \text{ J K}^{-1}$

- (i) Calculate the mean kinetic energy of an air molecule under these conditions.

(2)

- (ii) Calculate the mean square speed for the air molecules.

(3)

- (iii) Explain why, when the temperature of the air is increased to 320 K, some of the molecules will have speeds much less than that suggested by the value you calculated in part (b)(ii).

(2)

(Total 10 marks)

Mark schemes

1

- (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.

2

(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

$$\text{Ans} = V_2 \times 151$$

1

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

$$CE \text{ mass} = 0.029 \times (b)(ii)$$

$$CE \text{ density} = (0.029 \times (b)(ii)) / 0.0016$$

$$\text{or } (18.1 \times (b)(ii))$$

2

- (c) the (average / mean / mean-square) speed of molecules increases (with absolute temperature) ✓
 as the mean kinetic energy is proportional to the (absolute) temperature
 Or
 Reference to $KE_{\text{mean}} = 3/2 kT$ ✓ but mean or rms must feature in the answer somewhere.

2

[9]

2

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

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

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

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

$$p = 1.70 \times 10^5 \text{ Pa} \checkmark$$

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]

3

- (a) The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).

High Level – Good to Excellent

An experiment with results and interpretation must be given leading to the measurement of absolute zero. The student refers to 5 or 6 points given below. However each individual point must stand alone and be clear. *The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.*

6 clear points = 6 marks

5 clear points = 5 marks

5-6

Intermediate Level – Modest to Adequate

An experiment must be given and appropriate measurements must be suggested. For 3 marks the type of results expected must be given. 4 marks can only be obtained if the method of obtaining absolute zero is given. *The grammar and spelling may have a few shortcomings but the ideas must be clear.*

4 clear points = 4 marks

3 clear points = 3 marks

3-4

Low Level – Poor to Limited

One mark may be given for any of the six points given below. For 2 marks an experiment must be chosen and some appropriate results suggested even if the details are vague. Any 2 of the six points can be given to get the marks. *There may be many grammatical and spelling errors and the information may be poorly organised.*

2 clear points = 2 marks

Any one point = 1 mark

1-2

The description expected in a competent answer should include:

1. Constant mass of gas (may come from the experiment if it is clear that the gas is trapped) and constant volume (or constant pressure).

For (point 1) amount / quantity / moles of gas is acceptable.

2. Record pressure (or volume) for a range of temperatures.(the experiment must involve changing the temperature with pressure or volume being the dependent variable).

For (point 2) no specific details of the apparatus are needed. Also the temperature recording may not be explicitly stated eg. record the pressure at different temperatures is condoned.

3. How the temperature is maintained / changed / controlled. (The gas must be heated uniformly by a temperature bath or oven – so not an electric fire or lamp).

4. Describe or show a graph of pressure against temperature (or volume against temperature) that is linear. The linear relationship may come from a diagram / graph or a reference to the Pressure Law or Charles' Law line of best fit is continued on implies a linear graph).

5. Use the results in a graph of pressure against temperature (or volume against temperature) which can be extrapolated to lower temperatures which has zero pressure (or volume) at absolute zero, which is at 0 K or -273°C (a reference to crossing the temperature axis implies zero pressure or volume).

For (points 4 and 5) the graphs referred to can use a different variable to pressure or volume but its relationship to V or P must be explicit.

In (point 5) the graph can be described or drawn.

6. Absolute zero is obtained using any gas (provided it is ideal or not at high pressures or close to liquification)

Or Absolute temperature is the temperature at which the volume (or pressure or mean kinetic energy of molecules) is zero / or when the particles are not moving.

Discount any points that are vague or unclear

(Second part of point 6) must be stated not just implied from a graph.

- (b) (i)
- The motion of molecules is random.
 - Collisions between molecules (or molecules and the wall of the container) are elastic.
 - The time taken for a collision is negligible (compared to the time between collisions).
 - Newtonian mechanics apply (or the motion is non-relativistic).
 - The effect of gravity is ignored or molecules move in straight lines (at constant speed) between collisions.

✓✓ any two

If more than 2 answers are given each wrong statement cancels a correct mark.

- (ii) **Escalate if the numbers used are 4000, 5000 and 6000 giving 25666666 or similar.**

$$\begin{aligned} &\text{mean square speed} \\ &= (2000^2 + 3000^2 + 7000^2) / 3 = \\ &20.7 \times 10^6 \\ &= 2.1 \times 10^7 \quad (\text{m}^2 \text{s}^{-2}) \end{aligned}$$

Common correct answers

$$20.7 \times 10^6$$

$$21 \times 10^6$$

$$2.07 \times 10^7$$

$$2.1 \times 10^7$$

$$20\,700\,000$$

$$21\,000\,000.$$

Possible escalation.

1

- (c) **Escalate if the question and answer line requires a volume instead of a temperature.**

$$\begin{aligned} &(\text{using meanKE} = 3RT / 2N_A) \\ &T = 2N_A \times \text{meanKE} / 3R \\ &= 2 \times 6.02 \times 10^{23} \times 6.6 \times 10^{-21} / 3 \times 8.31 \checkmark \\ &= 320 \text{ (K)} \checkmark (318.8 \text{ K}) \\ &\text{Or} \\ &(\text{meanKE} = 3kT / 2) \\ &T = 2 \times \text{meanKE} / 3k \\ &= 2 \times 6.6 \times 10^{-21} / 3 \times 1.38 \times 10^{-23} \checkmark \\ &= 320 \text{ (K)} \checkmark (318.8 \text{ K}) \end{aligned}$$

First mark for substitution into an equation.

Second mark for answer

Possible escalation.

Answer only can gain 2 marks.

2

[11]

4

- (a) (i) $n = PV/RT = 3.2 \times 10^5 \times 1.9 \times 10^{-3} / 8.31 \times 285$
 $n = 0.26 \text{ mol} \checkmark (0.257 \text{ mol})$

1

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

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

3 sig figs $\checkmark$ 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]

5

(a) (i) a collision in which kinetic energy is conserved **(1)**

(ii) molecules of a gas are identical

[or all molecules have the same mass] **(1)**

molecules exert no forces on each other except during impact **(1)**

motion of molecules is random

[or molecules move in random directions] **(1)**

volume of molecules is negligible (compared to volume of container)

[or very small compared to volume of container or point particles] **(1)**

time of collision is negligible (compared to time between collisions) **(1)**

Newton's laws apply **(1)**

large number of particles **(1)** (any two)

3

(b) (i) the hot gas cools and cooler gas heats up

until they are at same temperature

hydrogen molecules transfer energy to oxygen molecules

until **average k.e.** is the same

(any two **(1) (1)**)

(ii) (use of $E_k = \frac{3}{2} kT$ gives) $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 420$ **(1)**

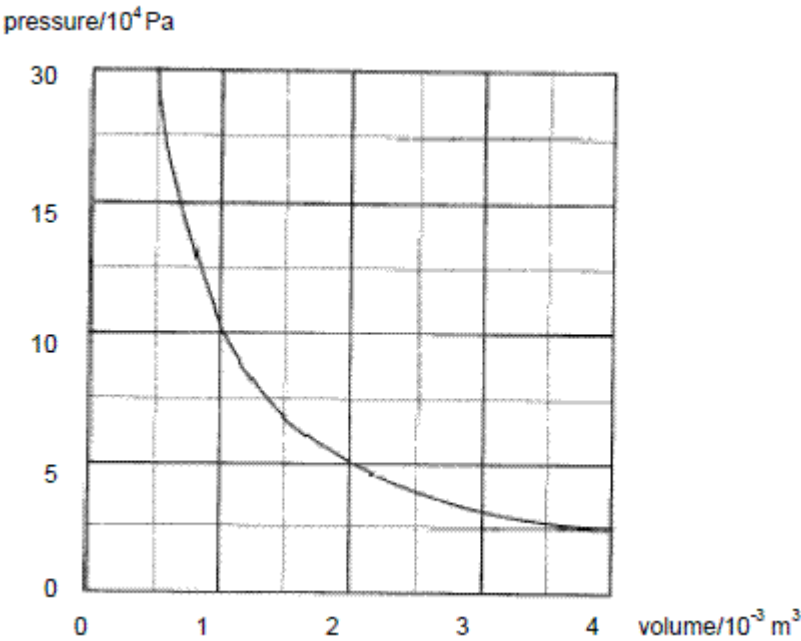
$= 8.7 \times 10^{-21} \text{ J}$ ($8.69 \times 10^{-21} \text{ J}$)

4

[7]

6

(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]

7

(a) (i) $pV = nRT$ **(1)**

(ii) all particles identical or have same mass **(1)**
 collisions of gas molecules are elastic **(1)**
 inter molecular forces are negligible (except during collisions) **(1)**
 volume of molecules is negligible (compared to volume of container) **(1)**
 time of collisions is negligible **(1)**
 motion of molecules is random **(1)**
 large number of molecules present
 (therefore statistical analysis applies) **(1)**
 monatomic gas **(1)**
 Newtonian mechanics applies **(1)**

max 4

(b) $E_k = \frac{3RT}{2N_A}$ or $\frac{3}{2}kT$ (1)

$$= \frac{3 \times 8.31 \times 293}{2 \times 6.02 \times 10^{23}} \text{ (1)}$$

$$= 6.1 \times 10^{-21} \text{ J (1) } (6.07 \times 10^{-21} \text{ J})$$

3

- (c) masses are different (1)
hence because E_k is the same,
mean square speeds must be different (1)

2

[9]

8

(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]

9

- (a) p : pressure and V : volume **(1)**
 N : number of molecules **(1)**
 m : mass of one molecule / particle / atom **(1)**
 $\overline{c^2}$: mean square speed **(1)**

4

- (b) (i) molecules have a range of speeds **(1)**
 they have no preferred direction of movement **(1)**
- (ii) elastic collisions
 intermolecular forces are negligible (except during collisions)
 volume of molecules negligible (compared to volume of container)
 time of collisions negligible (compared to time between collisions)
 all molecules identical
 laws of statistics apply or large number of molecules
 Newtonian laws apply
- any two **(1) (1)**

max 3

- (c) molecules collide (with the walls) **(1)**
 walls exert a force on the molecules **(1)**
 molecules exert an (equal) force (on the walls) **(1)**
 creating pressure **(1)**
 molecule momentum changes

max 4

[11]

10

- (a) (i) graph:

scales (points spread over at least half graph paper, each) **(1)**
 correct points (plotted within $\frac{1}{2}$ square) **(1)**
 best fit line (if origin shown, line must pass through it) **(1)**

$$E_k \text{ at } 350 \text{ K} = 7.22 \times 10^{-21} \text{ J (accept } 7.23 \text{ to } 7.27) \text{ (1)}$$

$$(ii) \text{ gradient } (= \frac{(8.28 \times 6.21)10^{-21}}{400 - 300})$$

$$= 2.07 \times 10^{-23} (\text{JK}^{-1}) \text{ (accept } 2.00 \text{ to } 2.15)$$

$$(\text{use of } \frac{3}{2} kT = E_k \text{ gives) gradient} = \frac{3}{2} k \text{ (1) (accept C.E for gradient)}$$

$$k = (\frac{2 \times 2.07 \times 10^{-23}}{3}) = 1.38 \times 10^{-23} \text{ (1) J K}^{-1} \text{ (1)}$$

8

- (b) (i) kinetic energy is conserved **(1)**
- (ii) time of collision is negligible (compared to time between collisions)
 [or large number of molecules,
 volume negligible (compared to volume of container),
 no intermolecular forces,
 rapid random motion] **(1)**
- (iii) temperature proportional to E_k **(1)**
 at 0 K, E_k would be zero **(1)**
 [or sketch graph of E_k vs T / K to give straight line through origin **(1)**
 graph explained **(1)**]

4

[12]

11

- (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)

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

(1)

(b) kinetic energy of one atom $\frac{3}{2} kT$ **(1)** ($\frac{3}{2} \times 1.38 \times 10^{-23} \times T$)

one gram contains $\frac{1}{4} \times N_A (= 1.5 \times 10^{23})$ atoms **(1)**

total internal energy = $1.5 \times 10^{23} \times \frac{3}{2} \times 1.38 \times 10^{-23} \times 48 = 150 \text{ J}$ **(1)**

(3)

(c) energy of helium gas at 48 K is twice that of tennis ball
 $\therefore$ energies equal when helium gas has a temperature of 24 K **(1)**

(1)

[5]

14

A

[1]

15

(a) (i) collisions with/bombardment by air molecules
 (condone particles)

B1

1

(ii) motion of air molecules ("they are") random
 (in all directions)

B1

fast moving

B1

max 2

air molecules small or much smaller than smoke
 particles

B1

(b) (i) $3/2kT$ or substituted values (independent of powers)

do not allow all equations written

C1

$6.21 \times 10^{-21} \text{ J}$

A1

2

(ii) $pV = \frac{1}{3} Nm\langle c^2 \rangle$

C1

relates Nm/V to ρ

C1

$2.4 \times 10^5 \text{ m}^2\text{s}^{-2}$

A1

(allow compensation of $\frac{1}{2} m\langle c^2 \rangle$ for 1)

3

(iii) there will be a range of speeds

B1

there will be molecules with lower speeds
than mean /average
means higher and lower values

B1

2

[10]