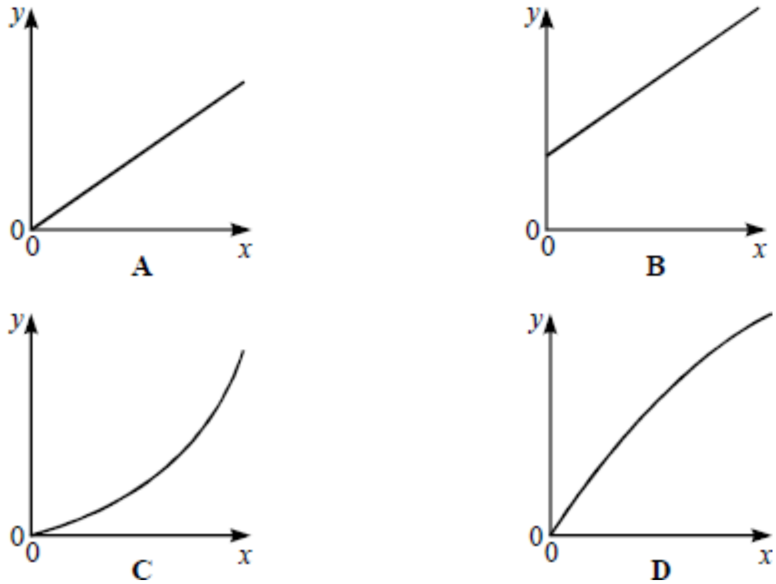
1 Which one of the graphs below shows the relationship between the internal energy of an ideal gas (y-axis) and the absolute temperature of the gas (x-axis)?



(Total 1 mark)

2 A fixed mass of an ideal gas initially has a volume V and an absolute temperature T. Its initial pressure could be doubled by changing its volume and temperature to

A $V/2$ and $4T$

B $V/4$ and $T/2$

C $2V$ and $T/4$

D $4V$ and $2T$

(Total 1 mark)

3 The temperature of a room increases from 283K to 293K. The r.m.s. speed of the air molecules in the room increases by a factor of

A 1.02

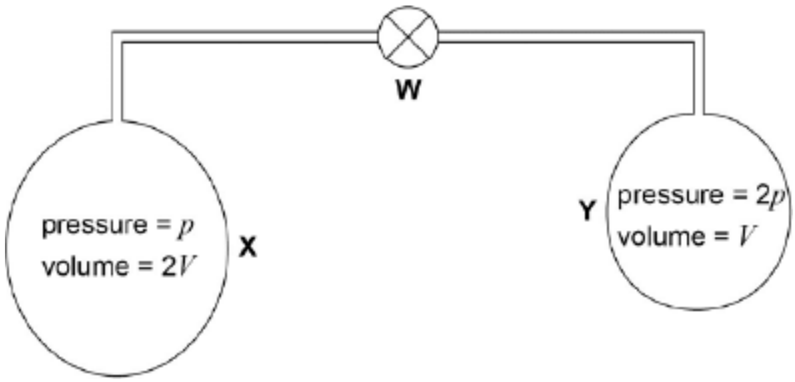
B 1.04

C 1.41

D 2.00

(Total 1 mark)

4 **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 $\frac{5}{3}p$ ○

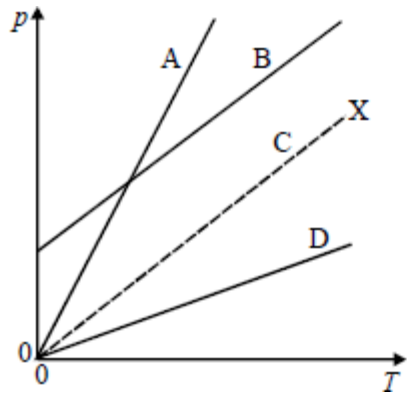
C $\frac{4}{3}p$ ○

D $\frac{3}{2}p$ ○

(Total 1 mark)

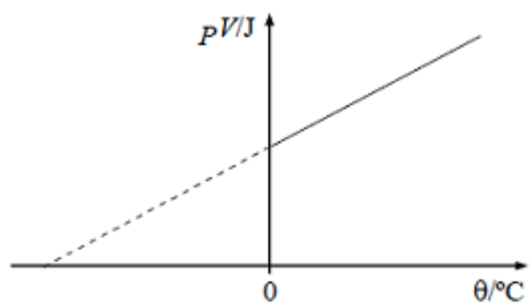
5 In the diagram the dashed line **X** shows the variation of pressure, p, with absolute temperature, T, for 1 mol of an ideal gas in a container of fixed volume.

Which line, **A**, **B**, **C** or **D** shows the variation for 2 mol of the gas in the same container?



(Total 1 mark)

6 The graph shows the relation between the product *pressure × volume*, pV, and temperature, θ, in degrees celsius for 1 mol of an ideal gas for which the molar gas constant is R.



Which one of the following expressions gives the gradient of this graph?

A $\frac{1}{273}$

B $\frac{pV}{\theta}$

C $\frac{pV}{(\theta - 273)}$

D R

(Total 1 mark)

7 At a certain temperature, the root-mean-square speed of the molecules of a fixed volume of an ideal gas is c. The temperature of the gas is changed so that the pressure is halved. The root-mean-square speed of the molecules becomes

A $\frac{c}{4}$

B $\frac{c}{2}$

C $\frac{c}{\sqrt{2}}$

D 2c

(Total 1 mark)

8 The number of molecules in one cubic metre of air decreases as altitude increases. The table shows how the pressure and temperature of air compare at sea-level and at an altitude of 10 000 m.

altitude	pressure/Pa	temperature/K
sea-level	1.0×10^5	300
10 000 m	2.2×10^4	270

(a) Calculate the number of moles of air in a cubic metre of air at

(i) sea-level,

....

....

(ii) 10 000 m.

....

....

(3)

(b) In air, 23% of the molecules are oxygen molecules. Calculate the number of extra oxygen molecules there are per cubic metre at sea-level compared with a cubic metre of air at an altitude of 10 000 m.

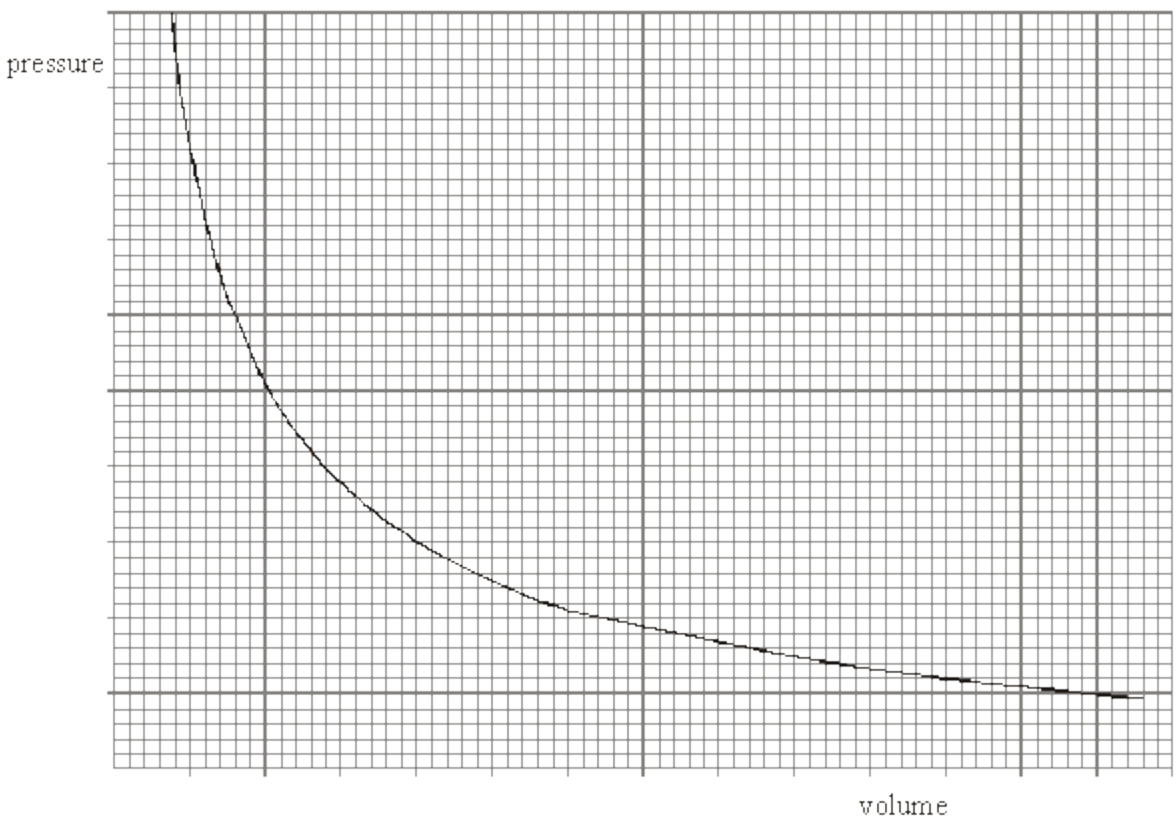
....

....

....

(2)
(Total 5 marks)

9 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)

10 The pressure inside a bicycle tyre of volume 1.90×10^{-3} m^3 is 3.20×10^5 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)

11 (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)

12 (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)

13 (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)

14 (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, $(c_{rms})^2$, 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)

15

Figure 1

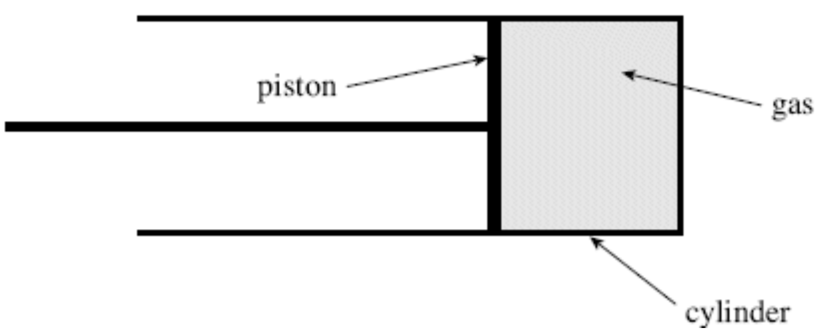
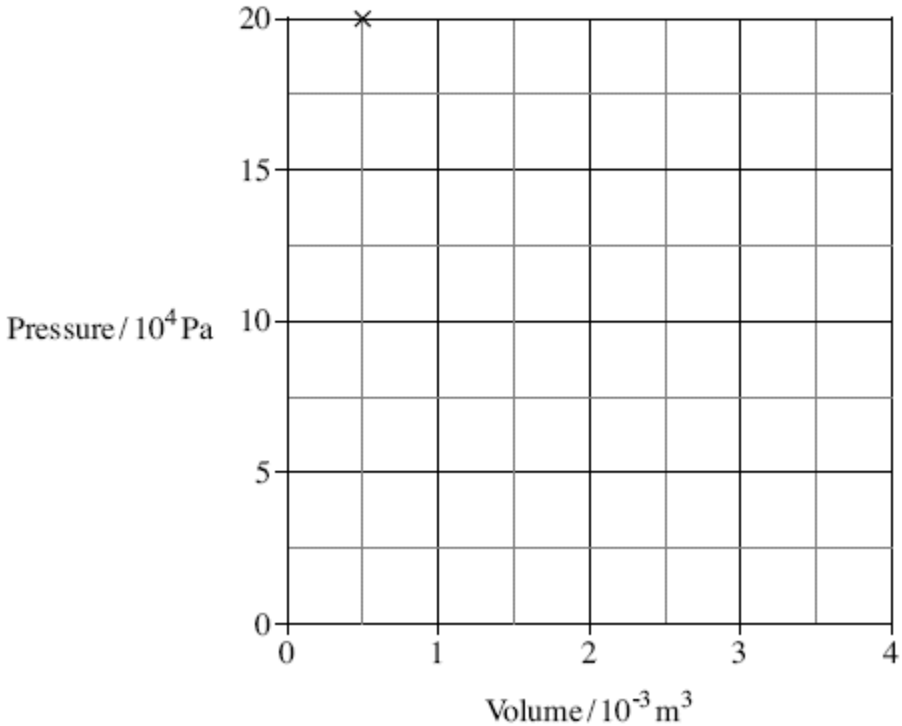


Figure 1 shows a cylinder, fitted with a gas-tight piston, containing an ideal gas at a constant temperature of 290 K. When the pressure, p, in the cylinder is 20×10^4 Pa the volume, V, is 0.5×10^{-3} m^3.

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)

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

....

....

....

....

(2)

(b) An ideal gas at a temperature of 22 °C is trapped in a metal cylinder of volume 0.20 m^3 at a pressure of 1.6×10^6 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 4.3×10^{-2} 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 °C and the pressure is 3.6×10^4 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)

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

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

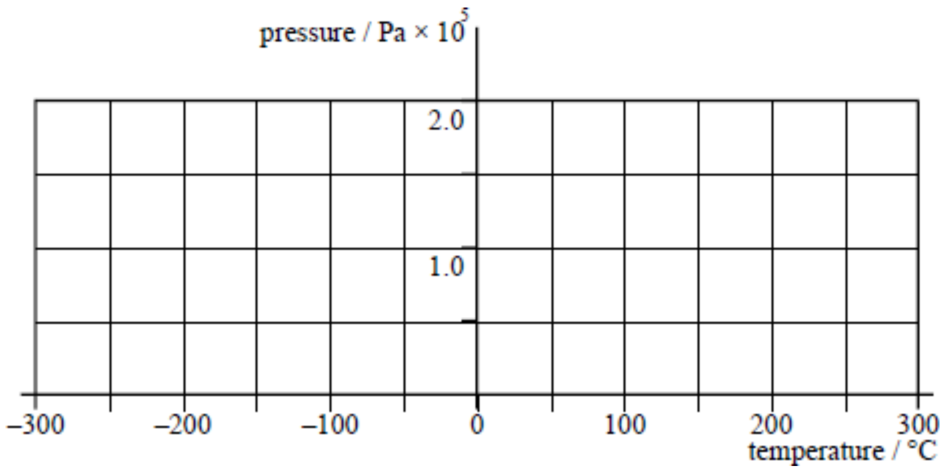
....

....

....

(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)

18 (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.

....

....

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....

(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.

....

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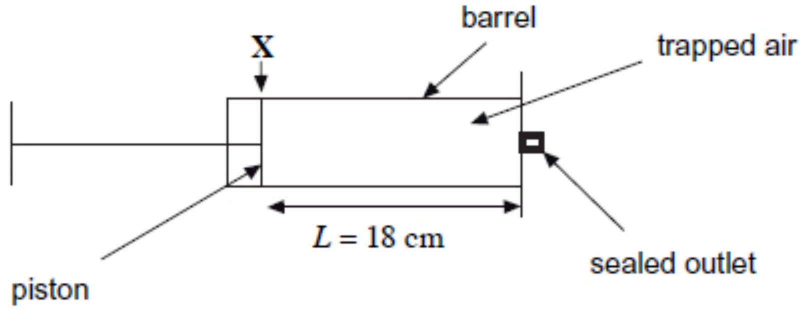
....

....

(6)
(Total 10 marks)

19 **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 1.7×10^{-4} m^3 when the piston is at position **X**. Under these conditions the trapped air is at a pressure p of 1.01×10^5 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 $\dfrac{\text{total volume of the air molecules}}{\text{volume occupied by the column of trapped air}}$ 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.

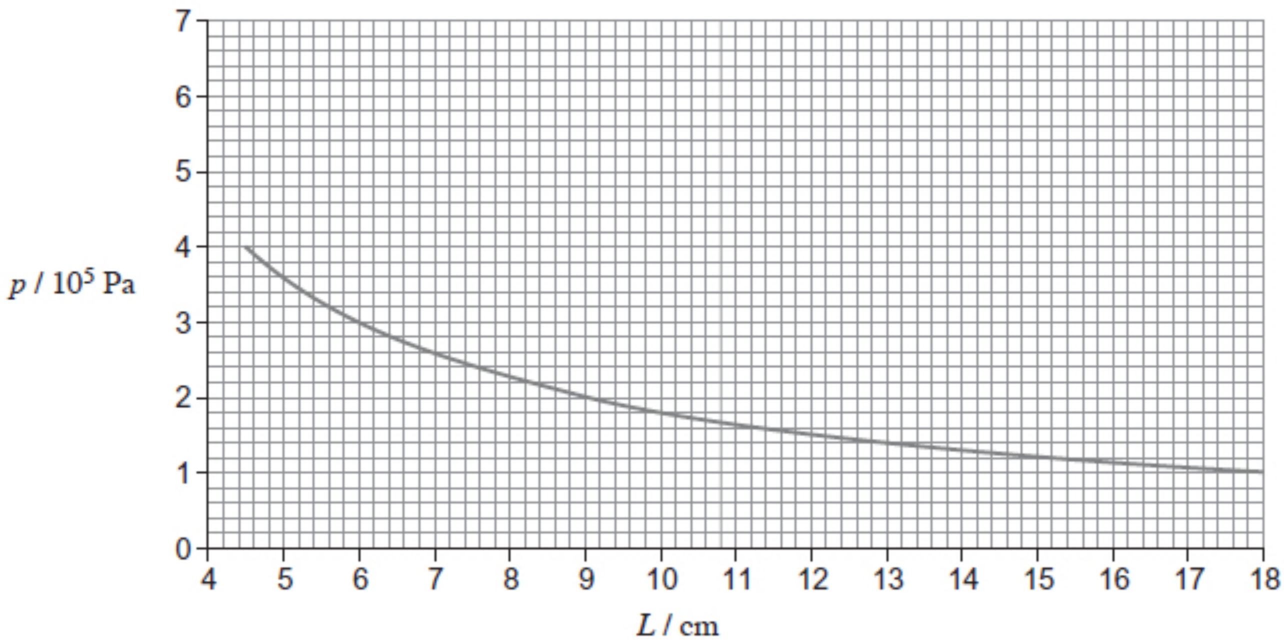
mean square speed .... unit ....

(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.

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(4)

(Total 22 marks)

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

....

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....

(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.

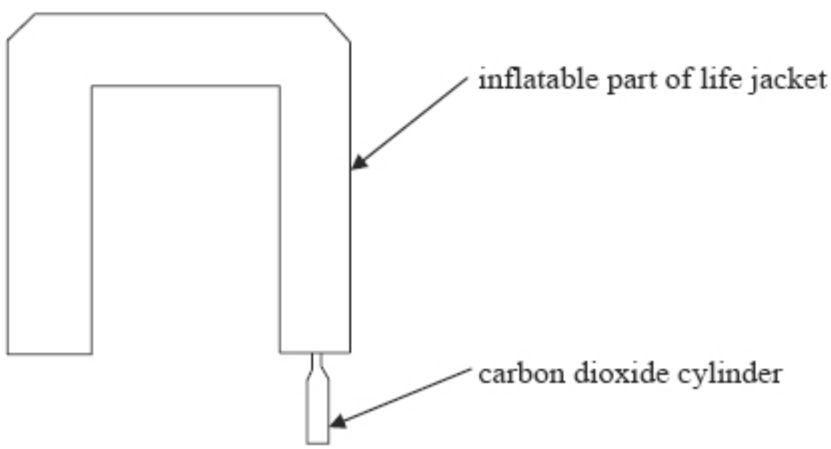
Assume that air behaves as an ideal gas and that the thickness of the material used for the ball is negligible.

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)

21 A life jacket inflates using gas released from a small carbon dioxide cylinder. The arrangement is shown in the following figure.



(a) The cylinder initially contains 1.7×10^{23} molecules of carbon dioxide at a temperature of 12 °C and occupying a volume of 3.0×10^{-5} m^3.

(i) Calculate the initial pressure, in Pa, in the carbon dioxide cylinder.

(ii) When the life jacket inflates, the pressure falls to 1.9×10^5 Pa and the final temperature is the same as the initial temperature. Calculate the new volume of the gas.

(iii) Calculate the mean molecular kinetic energy, in J, of the carbon dioxide in the cylinder.

(6)

(b) (i) Explain, in terms of the kinetic theory model, why the pressure drops when the carbon dioxide is released into the life jacket.

....

....

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....

....

....

(ii) Explain why the kinetic theory model would apply more accurately to the gas in the inflated life jacket compared with the gas in the small cylinder.

....

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(6)

(c) Explain, in terms of the first law of thermodynamics, how the temperature of the gas in the system can be the same at the beginning and the end of the process.

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....

(4)
(Total 16 marks)

22 (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 7.2×10^{-2} 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)

23 Nitrogen at 20°C and a pressure of 1.1×10^5 Pa is held in a glass gas syringe as shown in **Figure 1**. The gas, of original volume 8.5×10^{-5} m^3, is compressed to a volume of 5.8×10^{-5} m^3 by placing a mass on to the plunger of the syringe. The change in pressure of the gas is *adiabatic*. The new pressure of the gas is 1.9×10^5 Pa.

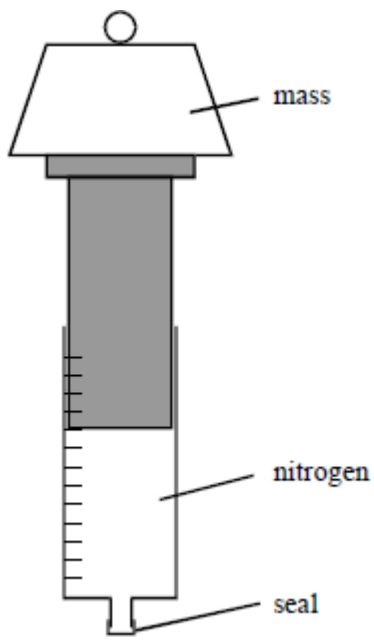


Figure 1

(a) (i) Calculate the new temperature of the nitrogen. Give your answer in °C.

(3)

(ii) Calculate the number of moles of nitrogen present in the syringe.

molar gas constant, R = 8.3 J mol^{-1} K^{-1}

(3)

(iii) The mass of the nitrogen in the syringe is 1.1×10^{-4} kg. Calculate the **mean square speed** of the molecules when the gas has been compressed.

(2)

(iv) Explain why the change in pressure of the nitrogen is adiabatic.

....

....

....

(2)

(v) Explain, in terms of the behaviour of the nitrogen molecules, how the gas exerts a greater pressure than it did before it was compressed.

....

....

....

....

....

....

(3)

(b) After the adiabatic compression, the nitrogen is allowed to cool at constant volume. **Figure 2** shows the variation of pressure with volume for the adiabatic compression and the subsequent cooling. The dotted line represents the isothermal compression that would have achieved the same final state.

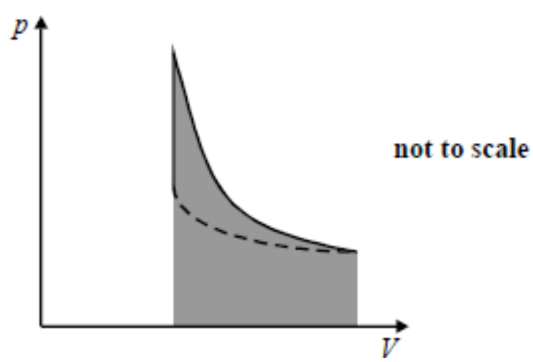


Figure 2

(i) Draw arrows on the graph to show the directions of the changes. Label your arrows **adiabatic compression** and **cooling** as appropriate.

(1)

(ii) State the significance of the shaded area of the graph.

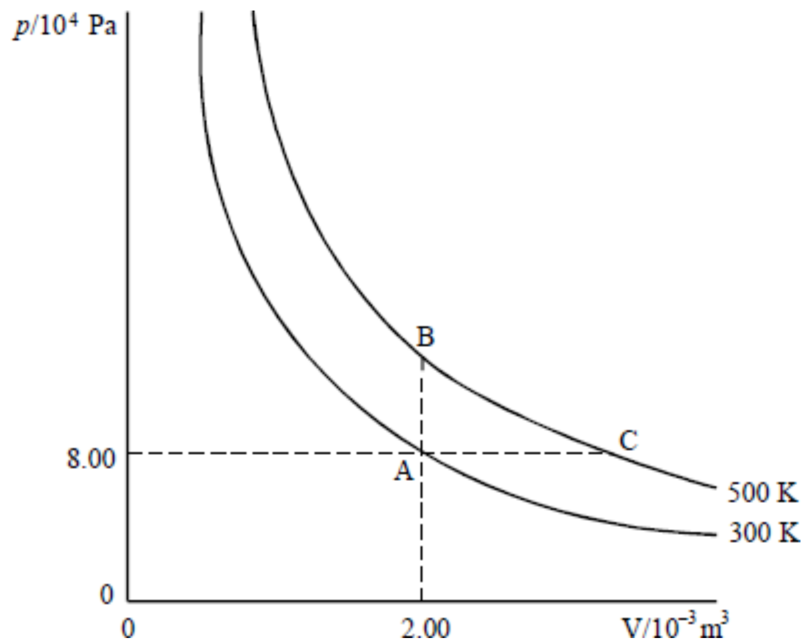
....

....

(1)
(Total 15 marks)

24 (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 J mol^{-1} 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

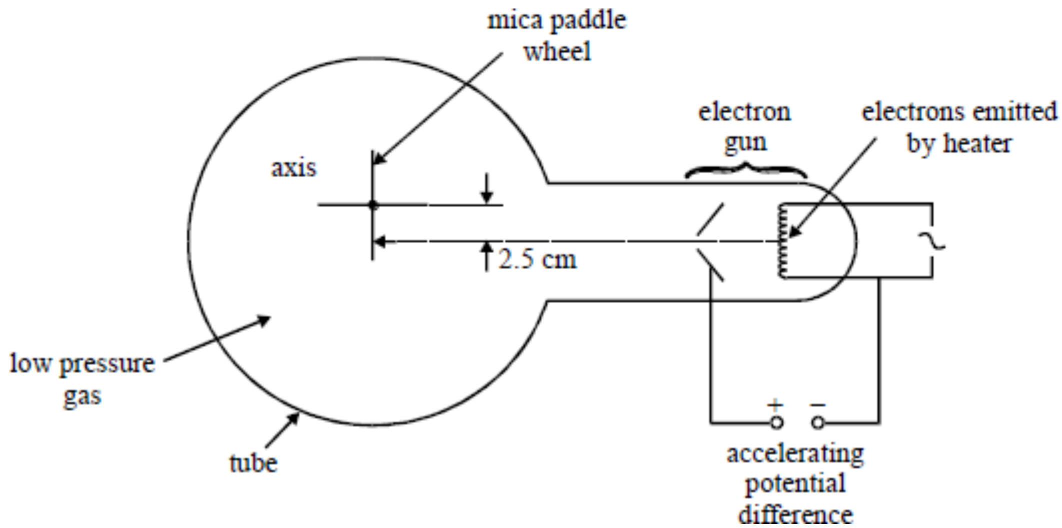
....

....

....

(3)
(Total 15 marks)

25 The diagram below shows an apparatus used to demonstrate that electron beams possess energy and momentum.



Electrons are accelerated by the electron gun and travel through the space in the tube which has been evacuated to a low pressure. They collide with the mica wheel and cause it to rotate.

(a) (i) Explain how the electrons would lose energy if the tube were not evacuated.

....

....

....

....

....

(3)

(ii) The pressure of the gas in the tube is 0.20 Pa when the room temperature is 300 K. The volume of the tube is 3.5×10^{-2} m^3. Determine the number of moles of gas in the tube.

universal gas constant, R = 8.3 J mol^{-1} K^{-1}

(2)

(iii) The Avogadro constant is 6.0×10^{23} mol^{-1}.

How many gas molecules are there in the tube?

....

(1)

(b) In the electron gun, the electrons of mass 9.1×10^{-31} kg and charge 1.6×10^{-19} C are accelerated to a speed of 2.7×10^{7} m s^{-1}. The beam current is 5.0 mA.

(i) Calculate, in J, the energy of each electron in the beam.

(1)

(ii) Use the definition of the volt to determine the potential difference through which the electrons are accelerated.

(2)

(iii) How many electrons are accelerated each second?

(2)

(iv) What happens to the energy of the electrons when they strike the mica target?

....

....

....

....

(2)

(v) Determine the force exerted on the paddle wheel by the electrons. Assume that the electrons are brought to rest when they collide.

(3)

(vi) The moment of this force about the axle of the paddle causes rotational acceleration of the paddle. What is the magnitude of this moment?

(2)
(Total 18 marks)

Mark schemes

1 A **[1]**

2 B **[1]**

3 A **[1]**

4 C **[1]**

5 A **[1]**

6 D **[1]**

7 C **[1]**

8

(a) (i) (use of $n = \frac{pV}{RT}$ gives) $n = \frac{1.0 \times 10^5 \times 1.0}{8.31 \times 300}$ **(1)**

= 40(.1) moles **(1)**

(ii) $n = \frac{2.2 \times 10^4 \times 1.0}{8.31 \times 270}$ = 9.8**(1)** moles **(1)**

3

(b) (total) = $(40 \times 6 \times 10^{23}) - (9.8 \times 6 \times 10^{23}) = 1.8(1) \times 10^{25}$ **(1)**

(allow C.E. for incorrect values of *n* from (a))

(oxygen molecules) = $0.23 \times 1.8 \times 10^{25} = 4.2 \times 10^{24}$ **(1)**

2

[5]

9 (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)**

$n = 11$ (mol) **(1)** (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)**

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

(iii) (no. of molecules) $N = 6.02 \times 10^{23} \times 10.8$ ($= 6.5 \times 10^{24}$)
total k.e. $= 6.5 \times 10^{24} \times 6.0 \times 10^{-21} = 3.9 \times 10^4$ J **(1)**
(allow C.E. for value of n and E_k from (i) and (ii))
(use of $n = 11$ (mol) gives total k.e. $= 3.9\ (7) \times 10^4$ J)

5

[7]

10

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

$n = 0.26$ mol ✓ (0.257 mol)

1

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

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

11 (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)**

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

4

[7]

12 (a) (i) T (=273 + 22) = 295 (K) **(1)**

(ii) $pV = nRT$ **(1)**
$105 \times 10^3 \times 27 = n \times 8.31 \times 295$ **(1)**
n = 1160 (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 = $1/3\rho\overline{c^2}$
decrease **(1)**
as ρ is constant **(1)**

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

max 4

[9]

13 (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)**
monamatic gas **(1)**
Newtonian mechanics applies **(1)**

max 4

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

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

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

3

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

2

[9]

14 (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 (= 3 / 2 *kT*) = 3 / 2 × 1.38 × 10^{-23} × (273 + 22)
= 6.1 × 10^{-21} (J) ✓

6 × 10^{-21} J is not given mark

1

(ii) mass of krypton atom
= 0.084 / 6.02 × 10^{+23} ✓
(= 1.4 × 10^{-25} kg)
$\overline{c^2}$ (= 2 × mean kinetic energy / mass

= 2 × 6.1 × 10^{-21} / 1.4 × 10^{-25})
= 8.7 - 8.8 × 10^4 ✓
$m^2 s^{-2}$ or J kg^{-1} ✓

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) × 1.43 × 10^{25}

3

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

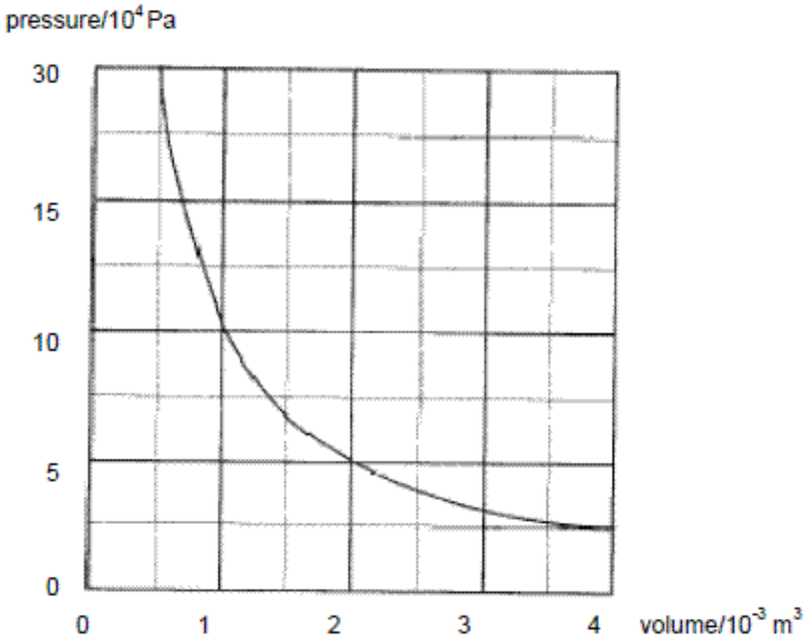
gases have equal $\frac{1}{2}mc_{rms}^2$
or
mass is inversely proportional to mean square speed / m ∝ 1 $/\overline{c^2}$ ✓
$\overline{c^2}$ or mean square speed of krypton is less ✓

1st mark requires the word <u>mean / average</u> 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]

15 (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

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

(total kinetic energy = mean kinetic energy × *N*)

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

= 150 (J) **(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]

16 (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 × 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) ($V_2 = P_1 V_1 T_2 / P_2 T_1$)
$V_2 = 1.6 \times 10^6 \times .200 \times (273 - 50) / 3.6 \times 10^4 \times (273 + 22)$ or 6.7(2) (m^3) ✓

allow ecf from bii

[reminder must see bii]
look out for

mass remaining = 5.61 × 0.20 / 6.72 = 0.17 (kg) ✓ (0.167 kg)
or
$n = (PV / RT = 3.6 \times 10^4 \times 0.200 / (8.31 \times (273 - 50)) = 3.88(5)$ (mol) ✓

mass remaining = $3.885 \times 4.3 \times 10^{-2} = 0.17$ (kg) ✓
2 sig figs ✓

any 2 sf answer gets the mark

3

[10]

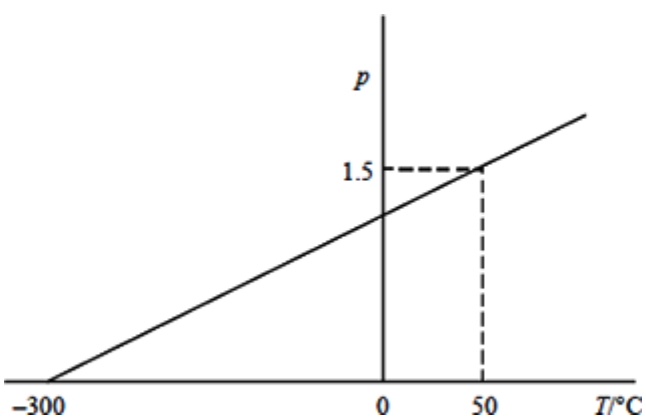
17

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

number of molecules = nN_A **(1)** = $6.71 \times 10^{-4} \times 6.02 \times 10^{23}$
= 4.04×10^{20} **(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

$$n\left(=\frac{pV}{RT}\right) = \frac{2.0\times10^5\times1.2\times10^{-5}}{8.31\times573}$$ **(1)** (= 5.04×10^{-4} mol)

∴ number of molecules left in container = $5.04\times10^{-4}\times6.02\times10^{23}$
= 3.03×10^{20} **(1)**

∴ number of molecules that escape = $4.04\times10^{20} - 3.03\times10^{20}$
= 1.01×10^{20} **(1)**

[*alternative (c)*
∴ number of moles that escape (= $6.71\times10^{-4} - 5.04\times10^{-4}$)
= 1.67×10^{-4}
∴ number of molecules that escape = $1.67\times10^{-4}\times N_A$
= 1.01×10^{20} **(1)**]

(3)

[9]

18 (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 = 300K **(1)**

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

= $1.5\times1.38\times10^{-23}\times300 = 6.2\times10^{-21}$ J **(1)**

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

(6)

[10]

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

3.47 × 10^{-2} or 3.5 × 10^{-2} (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 × 10^{-2}, 1.7 × 10^{-3}, 3.5 × 10^{-3} (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 × 10^{21} seen or 4.3 × 10^{21} seen

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

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

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

First mark condone T = 19

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

3

(iii) (NV=)1.7 × 10^{-4} × 7 × 10^{-4} or 1.19 × 10^{-7} seen

2.76 × 10^{-29} to 3.0 × 10^{-29} (m3) 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 ½ $m<c^2>$ =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 $<c^2>$ as subject including correct power 10
2.57×10^5 or 2.6×10^5 (on answer line)
m2 s^{-2}

Alternatively:

use of pV=1/3 Nm$<c^2>$ sub or rearrangement

Condone c_{rms} as subject for 1 mark

Condone power 10 error

Condone T = 19 in 1st MP

Correct sub with $<c^2>$ as subject including correct power 10

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

2.57×10^5 for N = 4.26×10^{21}

2.5(48) × 10^5 for N = 4.3×10^{21}

m^2 s^{-2}

condone alternative units where correct:

Pa m^3 kg^{-1}

J kg^{-1}

4

(c) (i) $p_1L_1 = k_1$ and $p_2L_2=k_2$

(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

$p_1L_1 = k_1$, $p_2L_2 = k_2$ *and* $p_3L_3 = k_3$

(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 = πr^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

$p = \frac{\frac{1}{3} N m \overline{c^2}}{\pi r 2 L}$ *or equivalent*

must be correct equation with V in terms of L

with p as subject

4

[22]

20 (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 = 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 K ✓ seen

volume of air = 5.55×10^{-3} m^3✓

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

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

$p = 1.70 \times 10^5$ Pa ✓

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

Allow ecf for their n V and T✓

6

[11]

21 (a) (i) $PV = NkT$ **(1)**

223×10^5 Pa **(1)**

2

(ii) pV = const or repeat calculation from (i) **(1)**

3.5×10^{-3} m^3 **(1)**

2

(iii) kinetic energy = 3/2 kT **(1)**

$5.9(0) \times 10^{-21}$ J **(1)**

2

(b) (i) volume increase **(1)**)
time between collisions increases **(1)**)
speed constant as temp constant **(1)**)
rate of change of momentum decreases **(1)**)

max 3

(ii) volume smaller in cylinder **(1)**

molecules occupy significantly greater proportion of the volume **(1)**

molecules closer so intermolecular forces greater **(1)**

3

(c) internal energy stays the same **(1)**

gas does work in expanding so *W* is negative **(1)**

gas must be heated to make *U* positive **(1)**

U and *W* equal and opposite **(1)**

4

[16]

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

$V = \frac{15 \times 8.13 \times 290}{500 \times 10^3}$ **(1)** (gives $V = 7.2 \times 10^{-2} m^3$)

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

$= 6.0 \times 10^{-21}$ (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 $p \propto n$]

$n = 13$ 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]

23 (a) (i) pV / T = constant in any form

C1

correct substitution including absolute temperatures / 345K

C1

72°C **not** 345K
condone no unit and condone just °

A1

(3)

(ii) $pV = nRT$ **C1**

correct substitution: $n = \frac{1.9 \times 10^5 \times 5.8 \times 10^{-5}}{8.3 \times 345}$ **or** $\frac{1.91 \times 10^5 \times 8.5 \times 10^{-5}}{8.3 \times 345}$ **C1**

$3.8(5) \times 10^{-3}$ (mol) **or** $3.8(4) \times 10^{-3}$ (mol) **A1**

e.c.f. for their (i)

(3)

(iii) $pV = \frac{1}{3} Nm<c^2$ **or** $p = \frac{1}{3} \rho<c^2$ **C1**

3.0×10^5 m^2 s^{-2} condone subsequent calculation of rms speed **A1**

(2)

(iv) no heat transfer / $\Delta Q = 0$ / no energy loss **B1**

process too quick (for conduction to take place) /
glass is poor (thermal) conductor / the system is isolated **B1**

(2)

(v) molecules move faster / have more KE **B1**

greater number of collisions (per second) (between molecules and wall)
not between molecules **B1**

greater (rate of) change in momentum in each collision **B1**

(3)

(b) (i) anticlockwise arrows correctly labelled - both arrows needed **B1**

(3)

(ii) work done **on** the gas (during compression) **B1**

(1)

[15]

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

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

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

(3)

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

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

(ii) $p\Delta V = 8.0 \times 10^4 \times (3.3 - 2.0) \times 10^{-3}$ = 104 J **(1)**
$\therefore \Delta Q = \Delta U + p\Delta V$ = 263 J **(1)**

(3)

[15]

25 (a) (i) they would collide with atoms of gas

M1

losing energy by:
ionising the gas

A1

exciting gas molecules

A1

allow 1 for stating inelastic collisions

(3)

(ii) $pV = nRT$

C1

$n = 2.8 \times 10^{-6}$

A1

(2)

(iii) 1.7×10^{18}

B1

(their (ii) $\times 6.0 \times 10^{23}$)

(1)

(b) (i) energy $\frac{1}{2}mv^2 = 3.3 \times 10^{-16}$ J

B1

(1)

(ii) 1 volt = 1 Joule per coulomb

C1

or p.d. = energy gained by electron / charge on electron

2070 V or 2100 V

A1

(2)

(iii) number of electrons = current / e

C1

3.1×10^{16}

A1

(2)

(iv) it produces heating of the mica

B1

it causes (rotation) kinetic energy of the mica paddle

B1

(2)

(v) force = change in momentum per second

C1

change in momentum per collision = 2.46×10^{-23} (N s)

C1

force = their (iii) × their momentum (7.6×10^{-7} N)

A1

(3)

(vi) moment = force × perpendicular distance

C1

1.9×10^{-8} N m

A1

(2)

[18]