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

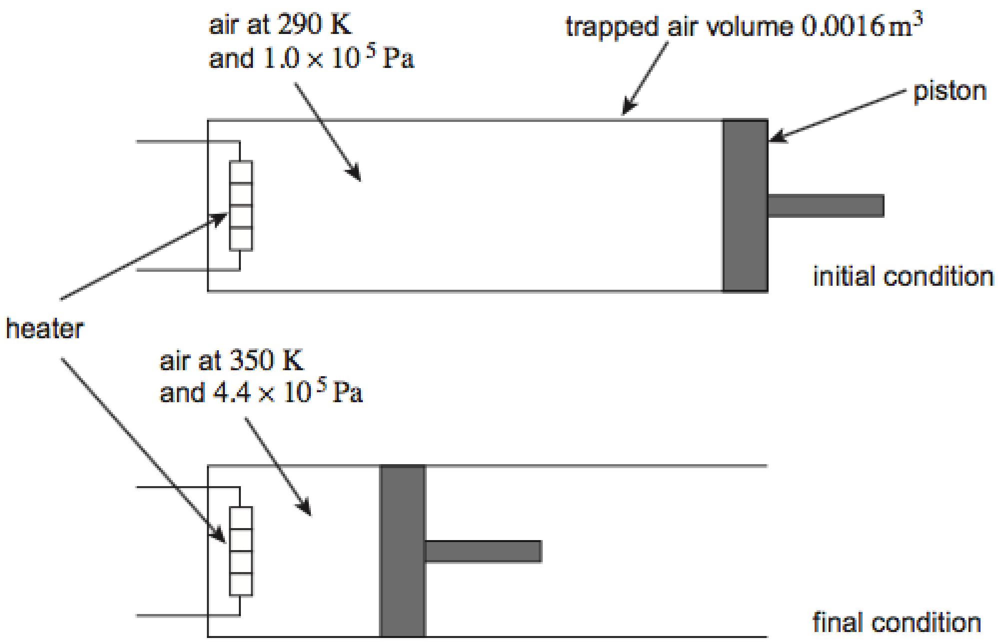
State **two** conditions necessary to complete the statement.

1. ____

2. ____

(2)

(b) A volume of 0.0016 m^3 of air at a pressure of 1.0×10^5 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 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.

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(2)

(Total 9 marks)

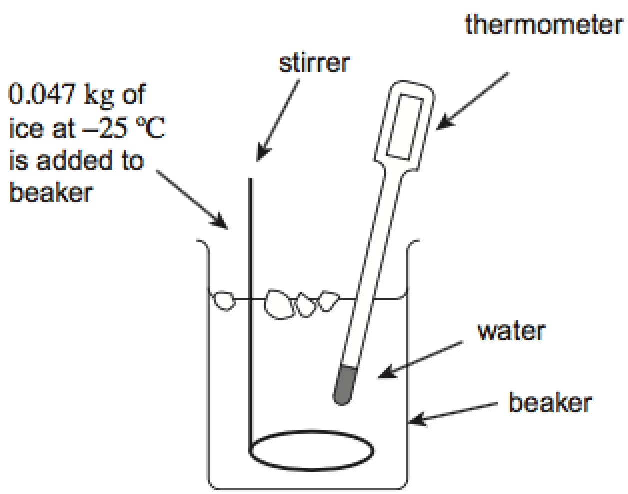
2 (a) Which statement explains why energy is needed to melt ice at 0°C to water at 0°C?

Place a tick (✓) in the right-hand column to show the correct answer.

	✓ if correct
It provides the water with energy for its molecules to move faster.	
It breaks all the intermolecular bonds.	
It allows the molecules to vibrate with more kinetic energy.	
It breaks some intermolecular bonds.	

(1)

(b) The diagram shows an experiment to measure the specific heat capacity of ice.



A student adds ice at a temperature of –25°C to water. The water is stirred continuously. Ice is added slowly until all the ice has melted and the temperature of the water decreases to 0°C. The mass of ice added during the experiment is 0.047 kg.

(i) Calculate the energy required to melt the ice at a temperature of 0°C.
The specific latent heat of fusion of water is 3.3×10^5 J kg^{-1}.

energy = ____________________ J

(1)

(ii) The water loses 1.8×10^4 J of energy to the ice during the experiment.
Calculate the energy given to the ice to raise its temperature to 0°C. Assume that no energy is transferred to or from the surroundings and beaker.

energy = ____________________ J

(1)

(iii) Calculate the specific heat capacity of the ice.
State an appropriate unit for your answer.

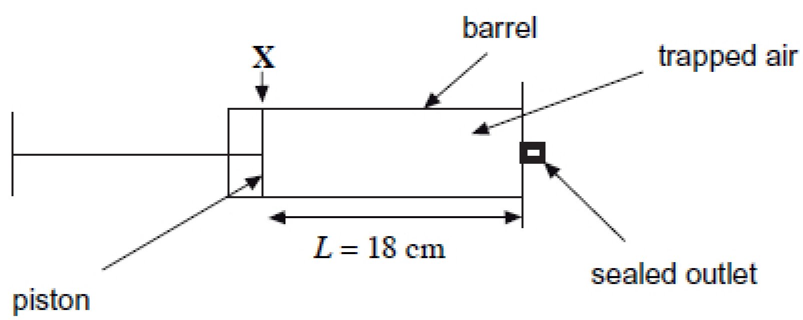
specific heat capacity = ____________________ unit = __________

(2)

(Total 5 marks)

3 **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 $1.7 \times 10^{-4} m^3$ 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.

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(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.

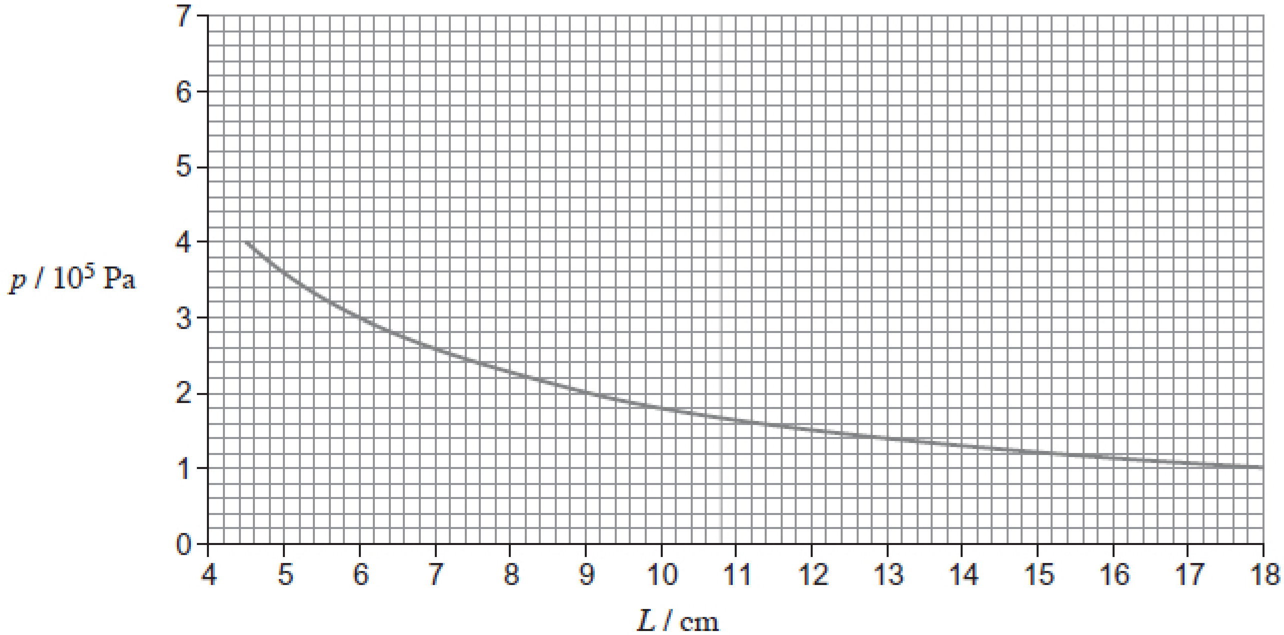
mean square speed ____________________ unit ___________

(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)

4 (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)

5 (a) Lead has a specific heat capacity of 130 J kg^{-1} K^{-1}.

Explain what is meant by this statement.

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(1)

(b) Lead of mass 0.75 kg is heated from 21 °C to its melting point and continues to be heated until it has all melted.

Calculate how much energy is supplied to the lead.
Give your answer to an appropriate number of significant figures.

melting point of lead = 327.5 °C
specific latent heat of fusion of lead = 23 000 J kg^{-1}

energy supplied ____________________ J

(3)

(Total 4 marks)

6 (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, $pV = \frac{1}{3} N m (c_{rms})^2$ 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 ____________________ m^2 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)

7 In stars, helium-3 and helium-4 are formed by the fusion of hydrogen nuclei. As the temperature rises, a helium-3 nucleus and a helium-4 nucleus can fuse to produce beryllium-7 with the release of energy in the form of gamma radiation.

The table below shows the masses of these nuclei.

Nucleus	**Mass / u**
Helium-3	3.01493
Helium-4	4.00151
Beryllium-7	7.01473

(a) (i) Calculate the energy released, in J, when a helium-3 nucleus fuses with a helium-4 nucleus.

energy released ____________________ J

(4)

(ii) Assume that in each interaction the energy is released as a single gamma-ray photon.

Calculate the wavelength of the gamma radiation.

wavelength ____________________ m

(3)

(b) For a helium-3 nucleus and a helium-4 nucleus to fuse they need to be separated by no more than 3.5×10^{-15} m.

(i) Calculate the minimum total kinetic energy of the nuclei required for them to reach a separation of 3.5×10^{-15} m.

total kinetic energy ____________________ J

(3)

(ii) Calculate the temperature at which two nuclei with the average kinetic energy for that temperature would be able to fuse.
Assume that the two nuclei have equal kinetic energy.

temperature ____________________ K

(3)

(c) Scientists continue to try to produce a viable fusion reactor to generate energy on Earth using reactors like the Joint European Torus (JET). The method requires a plasma that has to be raised to a suitable temperature for fusion to take place.

(i) State **two** nuclei that are most likely to be used to form the plasma of a fusion reactor.

1. ____

2. ____

(2)

(ii) State **one** method which can be used to raise the temperature of the plasma to a suitable temperature.

____

____

(1)

(Total 16 marks)

8 (a) Define the Avogadro constant.

____

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(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.

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(2)

(Total 7 marks)

9 (a) Define the specific latent heat of vaporisation of water.

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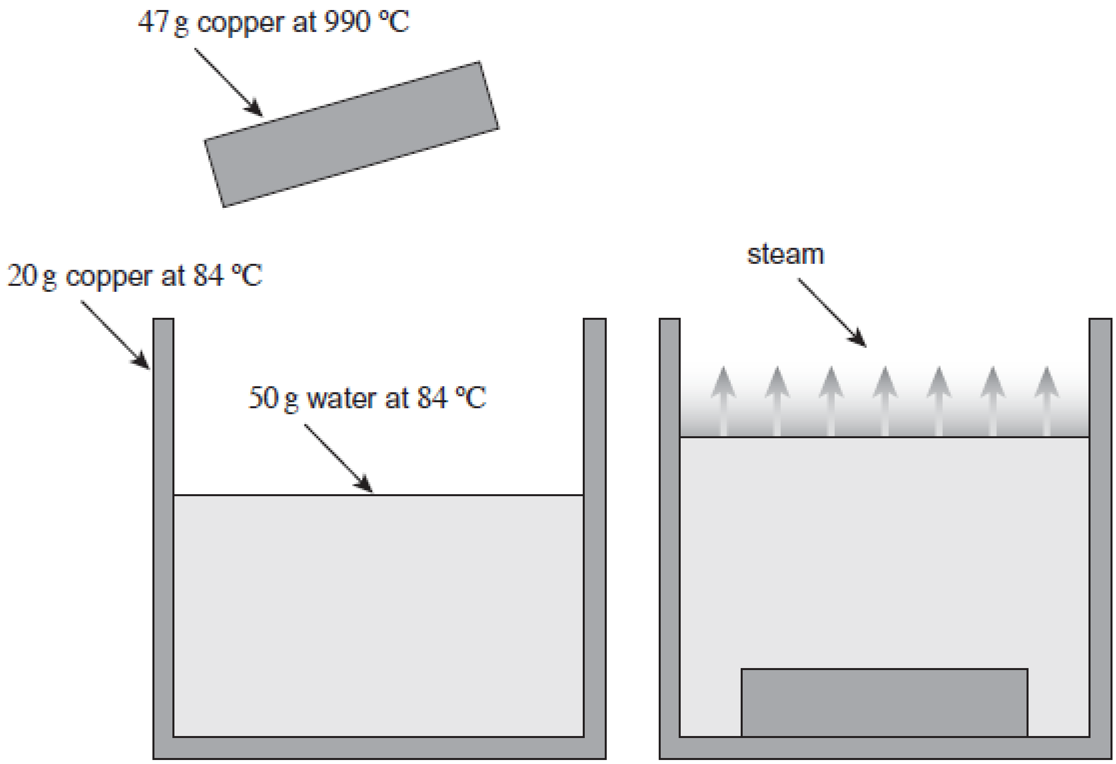
(2)

(b) An insulated copper can of mass 20 g contains 50 g of water both at a temperature of 84 °C. A block of copper of mass 47 g at a temperature of 990 °C is lowered into the water as shown in the figure below. As a result, the temperature of the can and its contents reaches 100 °C and some of the water turns to steam.

specific heat capacity of copper = 390 $\mathrm{J\,kg^{-1}\,K^{-1}}$
specific heat capacity of water = 4200 $\mathrm{J\,kg^{-1}\,K^{-1}}$
specific latent heat of vaporisation of water = 2.3×10^{6} $\mathrm{J\,kg^{-1}}$



Before placement After placement

(i) Calculate how much thermal energy is transferred from the copper block as it cools to 100 °C.
Give your answer to an appropriate number of significant figures.

thermal energy transferred ____________________ J

(2)

(ii) Calculate how much of this thermal energy is available to make steam.
Assume no heat is lost to the surroundings.

available thermal energy ____________________ J

(2)

(iii) Calculate the maximum mass of steam that may be produced.

mass ____________________ kg

(1)

(Total 7 marks)

10 A cola drink of mass 0.200 kg at a temperature of 3.0 °C is poured into a glass beaker. The beaker has a mass of 0.250 kg and is initially at a temperature of 30.0 °C.

specific heat capacity of glass = 840 J $kg^{-1}K^{-1}$
specific heat capacity of cola = 4190 J $kg^{-1}K^{-1}$

(i) Show that the final temperature, T_f, of the cola drink is about 8 °C when it reaches thermal equilibrium with the beaker.
Assume no heat is gained from or lost to the surroundings.

(2)

(ii) The cola drink and beaker are cooled from T_f to a temperature of 3.0 °C by adding ice at a temperature of 0 °C.
Calculate the mass of ice added.
Assume no heat is gained from or lost to the surroundings.

specific heat capacity of water = 4190 J kg^{-1} K^{-1}
specific latent heat of fusion of ice = 3.34×10^5 J kg^{-1}

mass ____________________ kg

(3)

(Total 5 marks)

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

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(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)

12 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 ____

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(2)

(Total 6 marks)

13 In a nuclear reactor the mean energy produced by each uranium-235 nucleus that undergoes induced fission is 3.0×10^{-11} J. In one pressurised water reactor, PWR, the fuel rods in the reactor contain 2.0×10^4 kg of uranium-235 and 40% of the energy produced per second is converted to 500 MW of electrical output power. It is assumed that all the energy produced in the reactor core is removed by pressurised water in the coolant system. The pressure of the water is approximately 150 times greater than normal atmospheric pressure. The water enters the reactor at a temperature of 275 °C ad leaves at a temperature of 315 °C. Under the operational conditions of the reactor the mean density of water in the coolant circuit is 730 kg m^{-3} and the specific heat capacity of water is approximately 5000 J kg^{-1} K^{-1}.

normal atmospheric pressure = 1.0×10^5 Pa
molar mass of uranium-235 = 0.235 kg

(a) The equation below gives one induced fission reaction that takes place in a reactor.

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{X} \Rightarrow ^{n}_{56}\mathrm{Br} + ^{90}_{p}\mathrm{Kr} + 2^{1}_{0}\mathrm{X}$$

(i) State the name of the particle represented by **X**.

____

(1)

(ii) State the proton and nucleon numbers represented by *p* and *n*.

p ______________________

n ______________________

(2)

(b) (i) Calculate the number of fission reactions that occur in the reactor each second.

number of fission reactions per second ______________________

(2)

(ii) The reactor fuel rods contain 2.0×10^4 kg of uranium-235. Assume that all this uranium-235 could be used.
Calculate the maximum time, in years, for which the reactor could operate.

time ______________________ years

(4)

(iii) Suggest why it is not possible to use all the uranium-235 in the reactor fuel rods.

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(2)

(c) Calculate the force exerted by the pressurised water on each square centimetre of the wall of the reactor.

force ______________________ N

(2)

(d) Calculate, in $m^3\ s^{-1}$, the flow rate of the water through the PWR reactor.
You will need to use data from the passage at the beginning of the question.

flow rate ______________________ $m^3\ s^{-1}$

(4)

(e) In a PWR the cooling water also acts as the moderator in the reactor and boron rods are used to control the power output. Describe the physical processes that take place in the moderator and control rods.

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(4)

(Total 21 marks)

14 An electrical heater is placed in an insulated container holding 100 g of ice at a temperature of –14 °C. The heater supplies energy at a rate of 98 joules per second.

(a) After an interval of 30 s, all the ice has reached a temperature of 0 °C. Calculate the specific heat capacity of ice.

answer = ______________________ $\mathrm{J\ kg^{-1}K^{-1}}$

(2)

(b) Show that the final temperature of the water formed when the heater is left on for a further 500 s is about 40 °C.

specific heat capacity of water = 4200 J $kg^{-1}K^{-1}$

specific latent heat of fusion of water = 3.3×10^5 J kg^{-1}

(3)

(c) The whole procedure is repeated in an uninsulated container in a room at a temperature of 25 °C.

State and explain whether the final temperature of the water formed would be higher or lower than that calculated in part (b).

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(2)

(Total 7 marks)

15

Figure 1

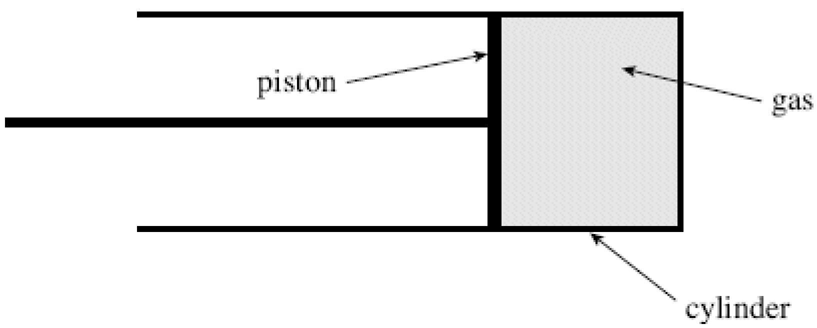
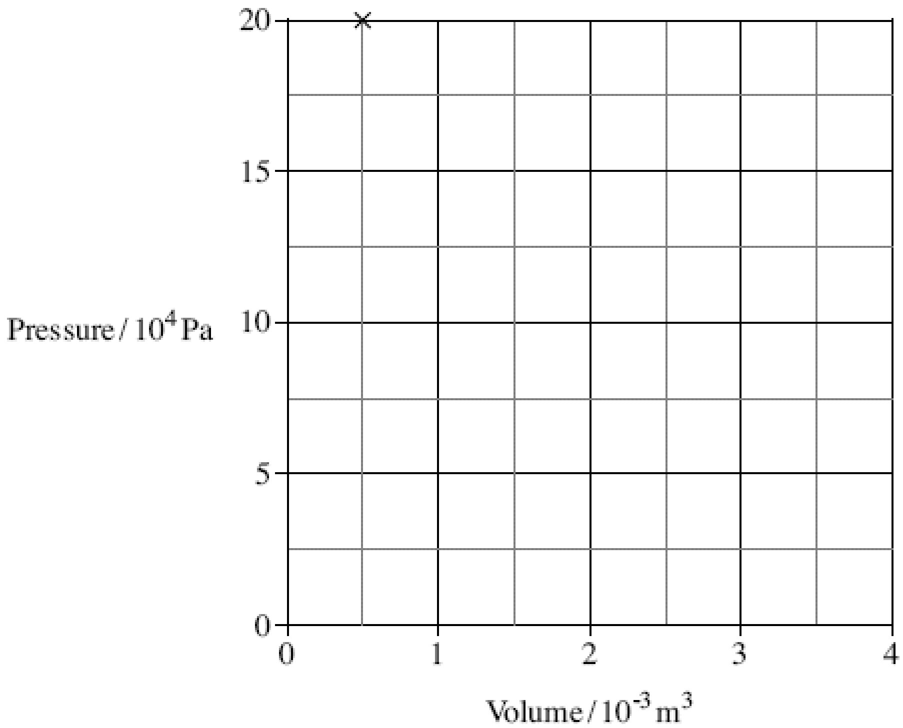


Figure 1 shows a cylinder, fitted with a gas-tight piston, containing an ideal gas at a constant temperature of 290 K. When the pressure, p, in the cylinder is 20×10^4 Pa the volume, V, is 0.5×10^{-3} m^3.

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) ____

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(iv) ____

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(4)

(Total 12 marks)

16 Molten lead at its melting temperature of 327°C is poured into an iron mould where it solidifies. The temperature of the iron mould rises from 27°C to 84°C, at which the mould is in thermal equilibrium with the now solid lead.

mass of lead = 1.20 kg
specific latent heat of fusion of lead = 2.5×10^4 J kg^{-1}
mass of iron mould = 3.00 kg
specific heat capacity of iron = 440 J $kg^{-1}K^{-1}$

(a) Calculate the heat energy absorbed by the iron mould.

answer = ______________________ J

(2)

(b) Calculate the heat energy given out by the lead while it is changing state.

answer = ______________________ J

(1)

(c) Calculate the specific heat capacity of lead.

answer = ______________________ J kg^{-1} K^{-1}

(3)

(d) State **one** reason why the answer to part (c) is only an approximation.

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(1)

(Total 7 marks)

17 In a geothermal power station, water is pumped through pipes into an underground region of hot rocks. The thermal energy of the rocks heats the water and turns it to steam at high pressure. The steam then drives a turbine at the surface to produce electricity.

(a) Water at 21°C is pumped into the hot rocks and steam at 100°C is produced at a rate of 190 kg s^{-1}.

(i) Show that the energy per second transferred from the hot rocks to the power station in this process is at least 500 MW.

specific heat capacity of water = 4200 J kg^{-1} K^{-1}
specific latent heat of steam = 2.3×10^6 J kg^{-1}

(ii) The hot rocks are estimated to have a volume of 4.0×10^6 m^3. Estimate the fall of temperature of these rocks in one day if thermal energy is removed from them at the rate calculated in part (i) without any thermal energy gain from deeper underground.

specific heat capacity of the rocks = 850 J kg^{-1} K^{-1}
density of the rocks = 3200 kg m^{-3}

(7)

(b) Geothermal energy originates as energy released in the radioactive decay of the uranium isotope $^{238}_{92}U$ deep inside the Earth. Each nucleus that decays releases 4.2 MeV.

Calculate the mass of $^{238}_{92}U$ that would release energy at a rate of 500 MW.

half-life of $^{238}_{92}U$ = 4.5×10^9 years

molar mass of $^{238}_{92}U$ = 0.238 kg mol^{-1}

(5)

(Total 12 marks)

18 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.

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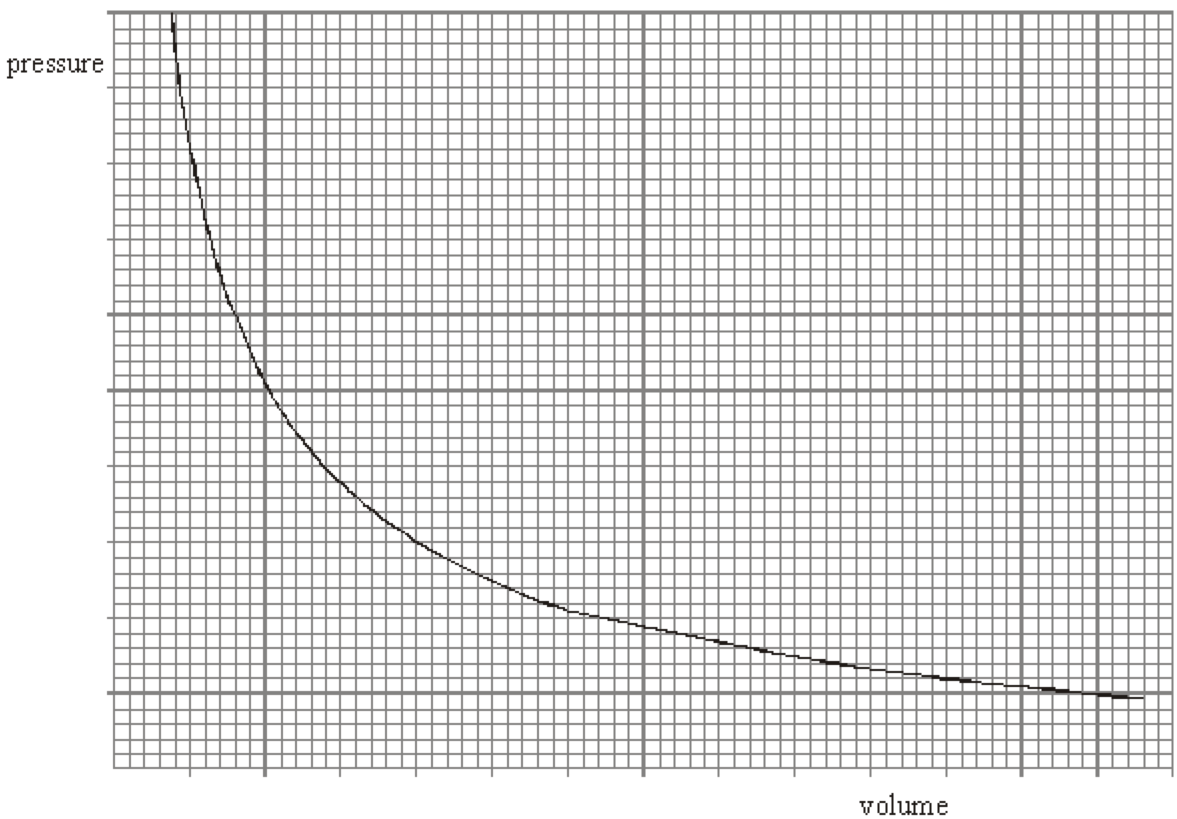
(2)

(Total 5 marks)

19 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)

20 (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)

21 (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,

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____

(ii) pressure of the gas.

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(4)
(Total 9 marks)

22 (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.

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(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)

23 (a) A 3.0 kW electric kettle heats 2.4 kg of water from 16°C to 100°C in 320 seconds.

(i) Calculate the electrical energy supplied to the kettle.

(ii) Calculate the heat energy supplied to the water.
specific heat capacity of water = 4200 J kg^{-1} K^{-1}

(iii) Give **one** reason why not all the electrical energy supplied to the kettle is transferred to the water.

(4)

(b) The potential difference supplied to the kettle in part (a) is 230 V.

(i) Calculate the resistance of the heating element of the kettle.

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(ii) The heating element consists of an insulated conductor of length 0.25 m and diameter 0.65 mm. Calculate the resistivity of the conductor.

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(5)

(Total 9 marks)

24 (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**.**

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

___

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(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.

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(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.

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(4)

(Total 10 marks)

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

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

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.

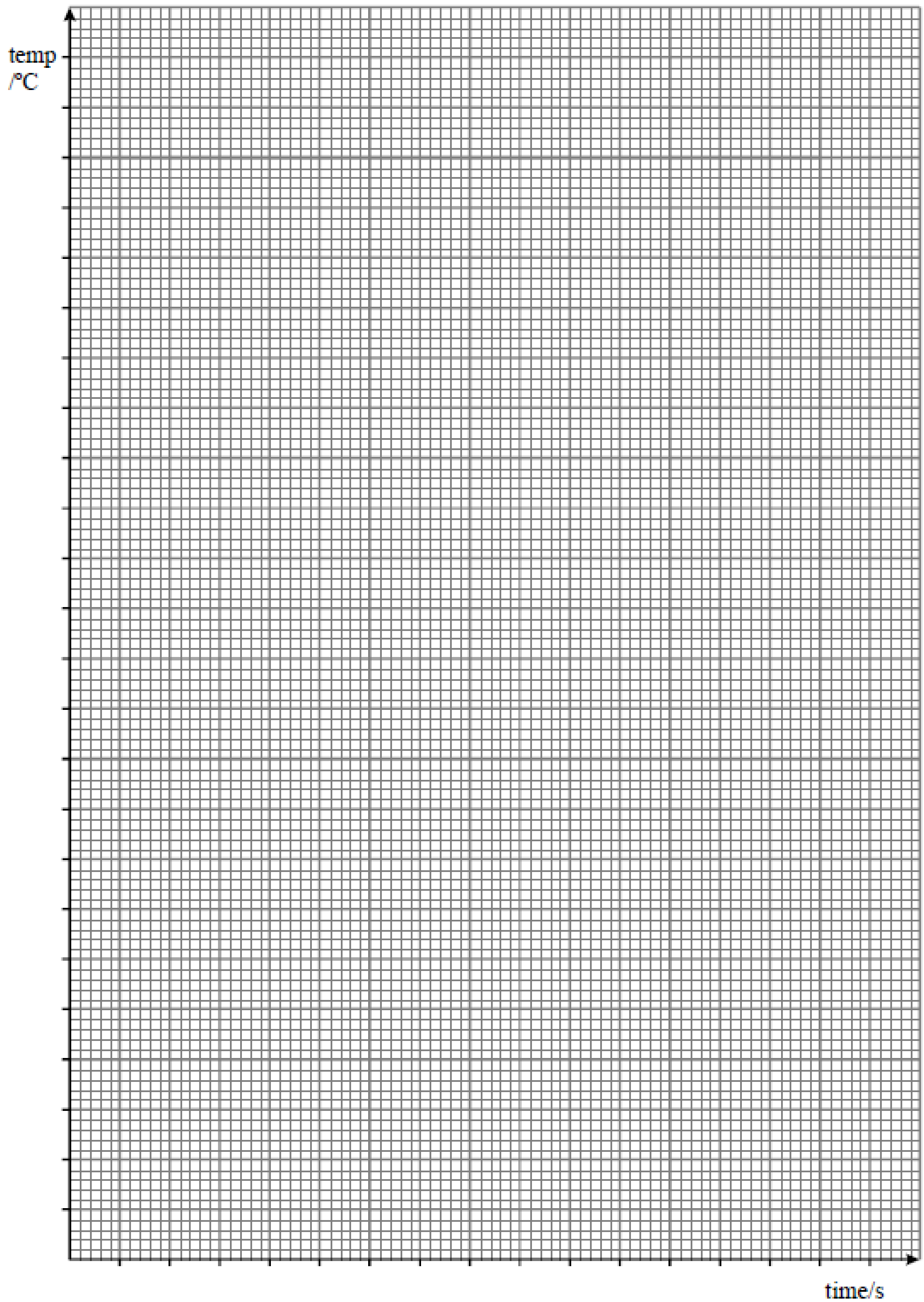
(4)

(Total 11 marks)

26 An electrical heater is used to heat a 1.0 kg block of metal, which is well lagged. The table shows how the temperature of the block increased with time.

temp / °C	20.1	23.0	26.9	30.0	33.1	36.9
time / s	0	60	120	180	240	300

(a) Plot a graph of temperature against time on the grid provided.



(3)

(b) Determine the gradient of the graph.

____

____

(2)

(c) The heater provides thermal energy at the rate of 48 W. Use your value for the gradient of the graph to determine a value for the specific heat capacity of the metal in the block.

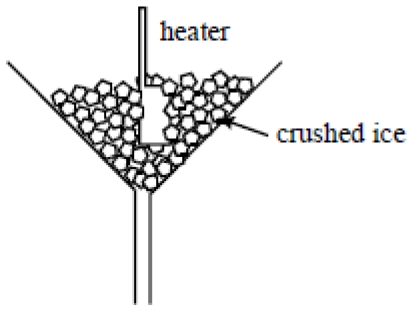
____

____

____

(2)

(d) The heater in part (c) is placed in some crushed ice that has been placed in a funnel as shown.



The heater is switched on for 200 s and 32 g of ice are found to have melted during this time. Use this information to calculate a value for the specific latent heat of fusion for water, stating **one** assumption made.

____

____

____

____

____

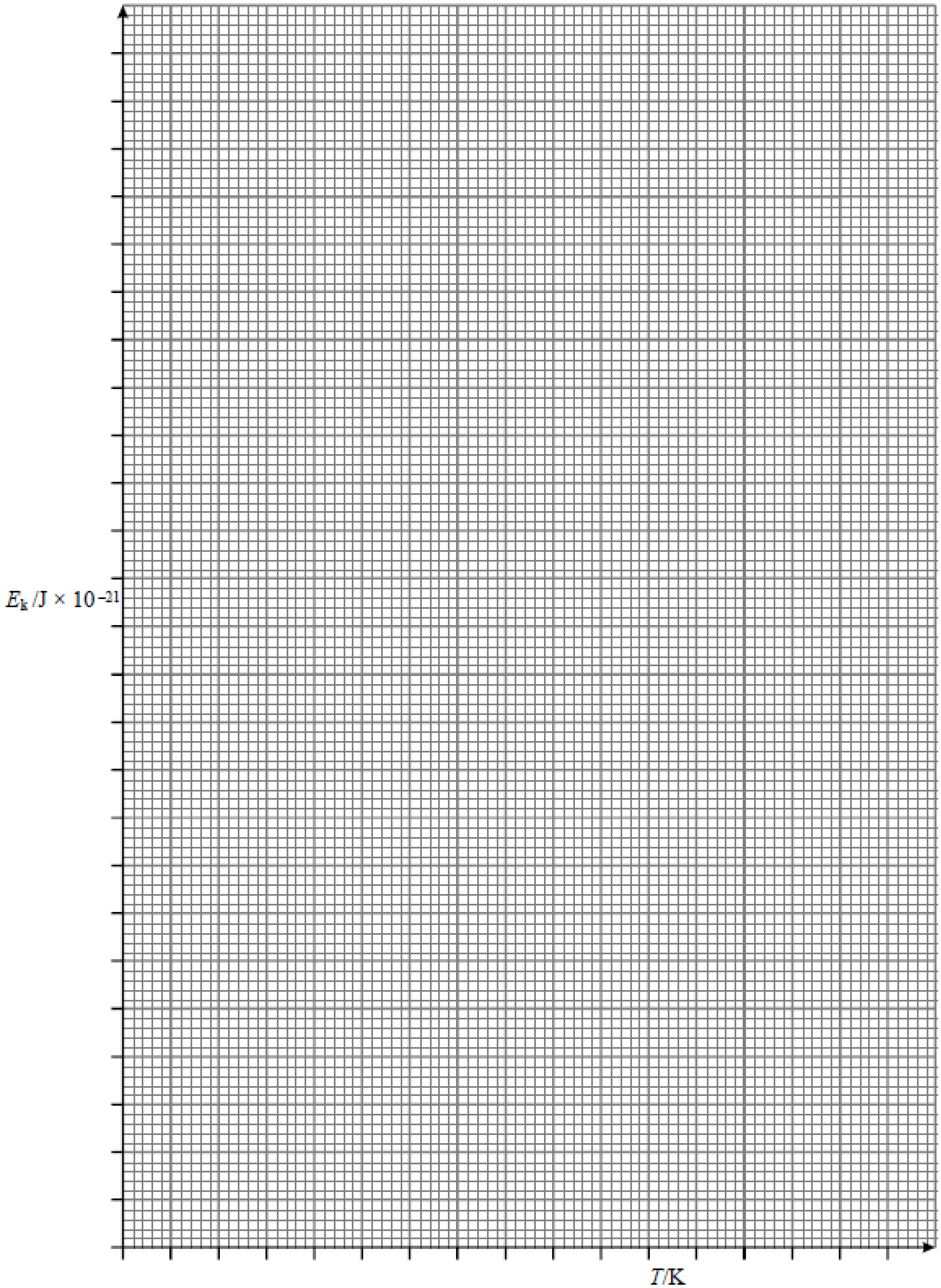
(3)

(Total 10 marks)

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

E_k/J × 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)

28 (a) State **two** quantities which increase when the temperature of a given mass of gas is increased at constant volume.

(i) ______________________________

(ii) ______________________________

(2)

(b) A car tyre of volume 1.0×10^{-2} m^3 contains air at a pressure of 300 kPa and a temperature of 290K. The mass of one mole of air is 2.9×10^{-2} kg. Assuming that the air behaves as an ideal gas, calculate

(i) n, the amount, in mol, of air,

(ii) the mass of the air,

(iii) the density of the air.

(5)

(c) Air contains oxygen and nitrogen molecules. State, with a reason, whether the following are the same for oxygen and nitrogen molecules in air at a given temperature.

(i) The average kinetic energy per molecule

(ii) The r.m.s. speed

(4)

(Total 11 marks)

29 (a) State the principle of conservation of linear momentum for two colliding bodies.

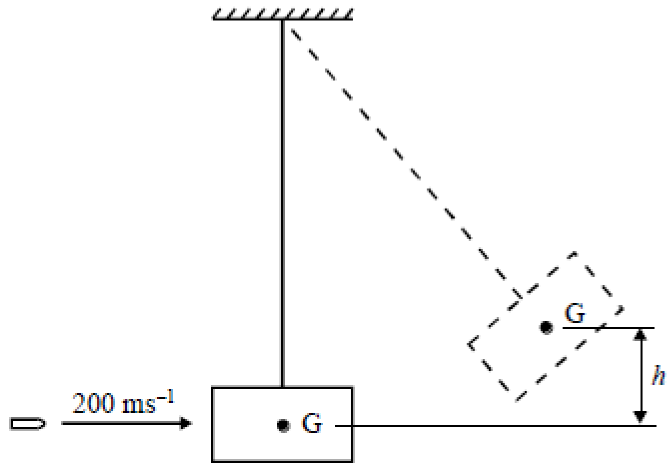
___

___

___

(2)

(b)



A bullet of mass 0.010 kg travelling at a speed of 200 m s^{-1} strikes a block of wood of mass 0.390 kg hanging at rest from a long string. The bullet enters the block and lodges in the block. Calculate

(i) the linear momentum of the bullet before it strikes the block,

___

(ii) the speed with which the block first moves from rest after the bullet strikes it.

___

___

(4)

(c) During the collision of the bullet and block, kinetic energy is converted into internal energy which results in a temperature rise.

(i) Show that the kinetic energy of the bullet before it strikes the block is 200 J.

___

(ii) Show that the kinetic energy of the combined block and bullet immediately after the bullet has lodged in the block is 5.0 J.

___

(iii) The material from which the bullet is made has a specific heat capacity of 250 J kg^{-1} K^{-1}. Assuming that all the lost kinetic energy becomes internal energy in the bullet, calculate its temperature rise during the collision.

____

____

____

(5)

(d) The bullet lodges at the centre of mass G of the block. Calculate the vertical height h through which the block rises after the collision.

____

____

____

(2)

(Total 13 marks)

30 (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)

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

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

$= 0.00044$ (m^3) ✓ (4.39×10^{-4} 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 (mol) ✓ (0.0667)
or
(use of $n = pV/RT$)
$= 1.0 \times 10^5 \times 0.0016 / (8.31 \times 290) = 0.066$ (mol) ✓ (0.0664)
or
$= 4.4 \times 10^5 \times 0.00044 / (8.31 \times 350) = 0.067$ (mol) ✓ (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 × number of moles)
mass = 0.029 × 0.0667 ✓ (0.00193 kg)
(density = mass / volume)
density = 0.00193 / 0.0016 = 1.2(1) kg m^{-3} ✓
(no continuation errors within this question but allow simple powers of 10 arithmetic errors which will lose one mark)

CE mass = 0.029 × (b)(ii)

CE density = (0.029 × (b)(ii)) / 0.0016

or (18.1 × (b)(ii)

2

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

2

[9]

2 (a) Tick in 4th box

1

(b) (i) (using heat energy = ml)
energy = 0.047 × 3.3 × 10^5 = 1.6 × 10^4 (J) ✓ (1.55 × 10^4 J)

answer alone gains mark

1

(ii) (heat in from water = heat supplied to melt and raise ice temperature)
1.8 × 10^4 = 1.6 × 10^4 + (energy to raise temp of ice)
energy to raise temp of ice = 2 × 10^3 (J) ✓

answer alone gains mark allow 2, 2.5 or 3 × 10^3 J

allow CE if substitution is shown

1.8 × 10^4 – (b)(i)

1

(iii) (using heat energy = $mc\Delta T$)
c = 2 × 10^3 / 0.047 × 25
= 2 × 10^3 ✓ (1.7 × 10^3) (note there is a large range of correct answers)
J kg^{-1} K^{-1} or J kg^{-1} $^oC^{-1}$ ✓ (allow use of dividing line but don't allow ^oK and $^oC^{-1}$ is not the same as C^{-1})

only allow CE if substitutions are seen

c = (b)(ii) / 0.047 × 25

= b(ii) × 0.851

allow 1 sig fig.

common answers:

for 2.5 × 10^3 J gives 2.1 × 10^3 or 2 × 10^3

for 3 × 10^3 J gives 2.6 × 10^3 or 3 × 10^3

2

[5]

3 (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 $m\langle c^2\rangle = 3/2\ kT$ 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)
m2 s^{-2}

Alternatively:

use of $pV = 1/3\ Nm\langle c^2\rangle$ 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) $p_1L_1 = k_1$ 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 <u>Rate of change</u> of momentum to increase

Increased <u>rate of change</u> of momentum causes <u>force</u> (exerted on walls) to <u>increase</u> (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]

4 (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]

5 (a) (it takes) 130 J / this energy to raise (the temperature of) a mass of 1 kg (of lead) by 1 K / 1 °C (without changing its state) ✓

1 kg can be replaced with unit mass.

Marks for 130J or energy.

+1 kg or unit mass.

+1 K or 1 °C.

Condone the use of 1 °K

1

(b) (using $Q = mc\Delta T + ml$)
$= 0.75 \times 130 \times (327.5 - 21) + 0.75 \times 23000$ ✓
(= 29884 + 17250)
= 47134 ✓
$= 4.7 \times 10^4$ (J) ✓

For the first mark the two terms may appear separately i.e. they do not have to be added.

Marks for substitution + answer + 2 sig figs (that can stand alone).

3

[4]

6 (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) <u>and</u> 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, <u>which is at 0 K or −273 °C</u> (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 <u>must</u> 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.

2

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

mean square speed
(= $(2000^2 + 3000^2 + 7000^2) / 3 =$
20.7×10^6)
$= 2.1 \times 10^7$ ($m^2\ s^{-2}$)

Common correct answers

20.7×10^6

21×10^6

2.07×10^7

2.1×10^7

20 700 000

21 000 000.

***Possible escalation**.*

1

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

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

First mark for substitution into an equation.

Second mark for answer

***Possible escalation**.*

Answer only can gain 2 marks.

2

[11]

7 (a) (i) (Mass change in u=) 1.71×10^{-3} (u)
or (mass Be−7) – (mass He−3) – (mass He−4) seen with numbers

C1

2.84×10^{-30} (kg)
or Converts their mass to kg

Alternative 2nd mark:
Allow conversion of 1.71×10^{-3} (u) to MeV by multiplying by 931 (=1.59 (MeV)) ***seen***

C1

Substitution in $E = mc^2$ *condone their mass <u>difference</u> in this sub but must have correct value for c^2 $(3\times10^8)^2$ or 9×10^{16}*

Alternative 3rd mark:
Allow their MeV converted to joules ($\times 1.6 \times 10^{-13}$) ***seen***

C1

2.55×10^{-13} (J) to 2.6×10^{-13} (J)

Alternative 4th mark:
Allow 2.5×10^{-13} (J) for this method

A1

4

(ii) Use of $E=hc/\lambda$ ***ecf***

C1

Correct substitution in rearranged equation with λ *subject* ***ecf***

C1

7.65×10^{-13} (m) to 7.8×10^{-13} (m) ecf

A1

3

(b) (i) Use of E_p formula:

C1

Correct charges for the nuclei **<u>and</u>** correct powers of 10

C1

$2.6(3) \times 10^{-13}$ J

A1

3

(ii) Uses KE = 3 / 2 kT: ***or*** *halves* KE_T, $KE = 1.3 \times 10^{-13}$ *(J)* ***seen ecf***

C1

Correct substitution of data **and** makes T subject **ecf**
Or uses KE_T value **and** divides T by 2

C1

6.35×10^9 (K) or 6.4×10^9 (K) or 6.28×10^9(K) or 6.3×10^9 (K) **ecf**

A1

3

(c) (i) Deuteron / deuterium / hydrogen−2

B1

Triton / tritium / hydrogen−3

B1

2

(ii) Electrical heating / electrical discharge / inducing a current in plasma / use of e−m radiation / using radio waves (causing charged particles to resonate)

B1

1

[16]

8 (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) = $3 / 2 \times 1.38 \times 10^{-23} \times (273 + 22)$
= 6.1×10^{-21} (J) ✓

6×10^{-21} J is not given mark

1

(ii) mass of krypton atom

$= 0.084 / 6.02 \times 10^{+23}$ ✓

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

$\overline{c^2}$ (= 2 × mean kinetic energy / mass

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

$= 8.7 - 8.8 \times 10^4$ ✓

$m^2\ s^{-2}$ 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]

9 (a) the energy required to change the state of a unit mass of water to steam / gas ✓
when at its boiling point temperature / 100°C / without a change in temperature) ✓

allow 1 kg in place of unit
allow liquid to vapour / gas without reference to water
don't allow 'evaporation' in first mark

2

(b) (i) thermal energy given by copper block (= $mc\Delta T$)
$= 0.047 \times 390 \times (990 - 100)$
$= 1.6 \times 10^4$ (J) ✓
2 sig figs ✓

can gain full marks without showing working
a negative answer is not given credit
sig fig mark stands alone

2

(ii) thermal energy gained by water and copper container
($= mc\Delta T_{water} + mc\Delta T_{copper}$)
$= 0.050 \times 4200 \times (100 - 84) + 0.020 \times 390 \times (100 - 84)$
or
= 3500 (J) ✓ (3485 J)
available heat energy ($= 1.6 \times 10^4 - 3500) = 1.3 \times 10^4$ (J) ✓

allow both 12000 J and 13000 J

allow CE from (i)
working must be shown for a CE
take care in awarding full marks for the final answer – missing out the copper container may result in the correct answer but not be worth any marks because of a physics error
(3485 is a mark in itself)
ignore sign of final answer in CE
(many CE's should result in a negative answer)

2

(iii) (using Q = ml)
$m = 1.3 \times 10^4 / 2.3 \times 10^6$
= 0.0057 (kg) ✓
Allow 0.006 but not 0.0060 (kg)

allow CE from (ii)
answers between 0.0052 → 0.0057 kg resulting from use of 12000 and 13000 J

1

[7]

10 (i) (heat supplied by glass = heat gained by cola)

(use of $m_g\, c_g\, \Delta T_g = m_c\, c_c\, \Delta T_c$)

1st mark for RHS or LHS of substituted equation

$0.250 \times 840 \times (30.0 - T_f) = 0.200 \times 4190 \times (T_f - 3.0)$ ✓

2nd mark for 8.4°C

$(210 \times 30 - 210\, t_f = 838\, T_f - 838 \times 3)$

$T_f = 8.4(1)$ (°C) ✓

Alternatives:

8°C is substituted into equation (on either side shown will get mark) ✓

resulting in 4620J~4190J ✓

or

8°C substituted into LHS ✓ *(produces ΔT = 5.5°C and hence)*

= 8.5°C ~ 8°C ✓

8°C substituted into RHS ✓

(produces ΔT = 20°C and hence)

= 10°C ~ 8°C ✓

2

(ii) (heat gained by ice = heat lost by glass + heat lost by cola)

NB correct answer does not necessarily get full marks

(heat gained by ice = $mc\Delta T + ml$)
heat gained by ice = $m \times 4190 \times 3.0 + m \times 3.34 \times 10^5$ ✓
(heat gained by ice = $m \times 346600$)

3rd mark is only given if the previous 2 marks are awarded

heat lost by glass + heat lost by cola
= $0.250 \times 840 \times (8.41 - 3.0) + 0.200 \times 4190 \times (8.41 - 3.0)$ ✓
(= 5670 J)

(especially look for $m \times 4190 \times 3.0$)
the first two marks are given for the formation of the substituted equation not the calculated values

m (=5670 / 346600) = 0.016 (kg) ✓

if 8°C is used the final answer is 0.015 kg

or (using cola returning to its original temperature)
(heat supplied by glass = heat gained by ice)
(heat gained by glass = $0.250 \times 840 \times (30.0 - 3.0)$)
heat gained by glass = 5670 (J) ✓
(heat used by ice = $mc\Delta T + ml$)
heat used by ice = $m(4190 \times 3.0 + 3.34 \times 10^5)$ ✓ (= m(346600))

m (=5670 / 346600) = 0.016 (kg) ✓

3

[5]

11 (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]

12

(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]

13

(a) (i) neutron

B1

1

(ii) p = 36

B1

n = 144

B1

2

(b) (i) total energy produced = $\frac{500 \times 100}{40}$ MJ each second

C1

number of reaction = 4.2×10^{19} per second

A1

2

(ii) 1 kg contains $(1000/235) \times 6.02 \times 10^{23}$ atoms of uranium

C1

total number of fissions = $(1000/235) \times 6.02 \times 10^{23} \times 2 \times 10^{4}$
(5.1×10^{28})

C1

time = total fissions available/number per second or 1.2×10^{9}s

C1

38.7(39) years

A1

4

(iii) too few neutrons produced to maintain the chain reaction

B1

probability of a neutron colliding with a uranium nucleus too low

B1

more absorption of neutrons in non–fission capture

B1

2

(c) pressure = 150×10^5 (Pa) or $F = PA$

C1

force on 1 cm ^{2} = 1500N

A1

2

(d) energy removed each second

$E = \frac{500 \times 100}{40}$ MJ = 1.25 × 109 J or $E = mc\Delta\theta$

C1

$1.25 \times 10^9 = m$ 5000 × 40

C1

mass per second = 6250 kg

C1

volume per second = 8.6(8.56) m^3

A1

4

(e) **control rods**

neutrons are absorbed

B1

by the nucleus of the boron/atoms

B1

moderator

neutrons are slowed down

B1

when colliding with the protons/hydrogen nucleus

B1

4

[21]

14

(a) (use of $\Delta Q = m\,c\,\Delta T$)

$30 \times 98 = 0.100 \times c \times 14$ ✓

$c = 2100$ (J kg^{-1} K^{-1}) ✓

2

(b) (use of $\Delta Q = m\,l + m\,c\,\Delta T$)

$500 \times 98 = 0.100 \times 3.3 \times 10^5$ ✓ $+ 0.100 \times 4200 \times \Delta T$ ✓

($\Delta T = 38$ °C)

T = 38°C ✓

3

(c) the temperature would be higher ✓

as the ice/water spends more time below 25°C

or heat travels in the direction from hot to cold

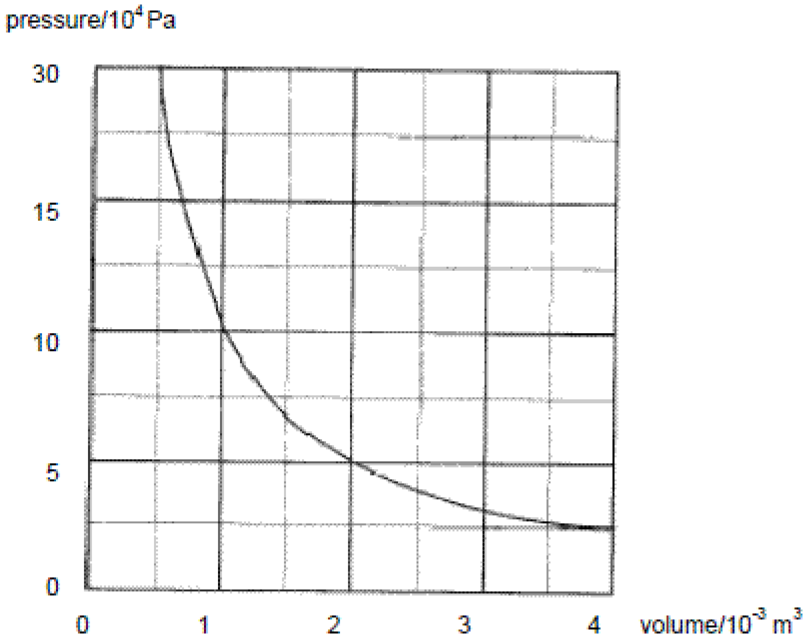
or ice/water first gains heat then loses heat

any **one** line ✓

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) using $Q = mc\Delta\theta$

= 3.00 × 440 × (84-27) **(1)**

7.5×10^{4} (J) **(1)**

2

(b) using $Q = ml$

= $1.20 \times 2.5 \times 10^{4}$

= 3.0×10^{4} (J) **(1)**

1

(c) (heat supplied by lead changing state + heat supplied by cooling lead = heat gained by iron)

3.0×10^4 + heat supplied by cooling lead = 7.5×10^4 **(1)**

heat supplied by cooling lead = $4.5 \times 10^4 = mc\Delta\theta$

$c = 4.5 \times 10^4/(1.2 \times (327 - 84)$ **(1)**

$c = 154$ (J kg^{-1} K^{-1}) **(1)**

3

(d) any **one** idea **(1)**

no allowance has been made for heat loss to the surroundings

or the specific heats may not be a constant over the range of temperatures calculated

1

[7]

17 (a) (i) heat water to 100 °C, energy (= 190 × 4200 × 79) = 63 (MJ) **(1)**
vapourise water, energy
(=190 × 2.3 × l0^6) = 440(MJ) **(1)**
(437MJ)

energy transferred (per sec) = (437 + 63) MJ **(1)**
(= 500 MJ)

(ii) mass of rocks (= $4.0 \times 10^6 \times 3200$)

= 1.3×10^{10}(kg) **(1)**

(1.28×10^{10})

temperature fall of ΔT in one day, energy removed
(= $1.28 \times 10^{10} \times 850 \times \Delta T$) = $1.1 \times 10^{13}\ \Delta T$ **(1)**

(1.09 x 10^{13} AT)
(allow C.E. for value of mass of rocks)

energy transfer in one day (= $500 \times 10^6 \times 3600 \times 24$)
= 4.3×10^{13} (J) **(1)**

in one day $\Delta T\left(= \frac{4.3 \times 10^{13}}{1.1 \times 10^{13}}\right) = 3.9(1)$ K **(1)**

7

(b) number of nuclei in 1 kg of ^{238}U $= \left(\frac{6.02 \times 10^{23}}{0.238}\right) = 2.5(3) \times 10^{24}$ **(1)**

activity of lkg of ^{238}U $= \frac{\ln 2}{T_{1/2}} \times 2.53 \times 10^{24}$ **(1)**

$\left(= \frac{\ln 2}{4.5 \times 10^{9} \times 3.1 \times 10^{7}} \times 2.53 \times 10^{24}\right) = 1.2(6) \times 10^{7} (s^{-1})$ **(1)**

energy released per sec per kg of ^{238}U

$= 1.2(6) \times 10^{7} \times 4.2 \times 1.6 \times 10^{-13}$(J) **(1)**

$(8.47 \times 10^{-6}$(J))

mass of ^{238}Uneeded $= \frac{500 \times 10^{6}}{8.47 \times 10^{-6}} = 5.9(0) \times 10^{13}$kg **(1)**

5

[12]

18 (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]

19 (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) $N = 6.02 \times 10^{23} \times 10.8$ (= 6.5×10^{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) × 10^4 J)

5

[7]

20 (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]

21 (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]

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

$= \dfrac{3 \times 8.31 \times 293}{2 \times 6.02 \times 10^{23}}$ **(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]

23 (a) (i) (use of $E = Pt$ gives) E = 3000 × 320 = 960 kJ **(1)**

(ii) (use of $Q = mc\Delta\theta$ gives) Q = 2.4 × 4200 (100 - 16) **(1)**
= 850 kJ **(1)**

(iii) energy needed to heat the kettle material **(1)**
[or heat loss to surroundings]

4

(b) (i) (use of $I = \dfrac{P}{V}$ gives) $I = \dfrac{3000}{230}$ = 13 (A) **(1)**

(use of $V = IR$ gives) $R\left(= \dfrac{230}{13}\right)$ = 18 Ω **(1)** (17.7 Ω)

(allow C.E. for value of I)
[or correct use of $R = \dfrac{V^2}{P}$ to give correct R]

(ii) $A = \pi \dfrac{(0.65 \times 10^{-3})^2}{4}$ (m^2) **(1)** (= 3.32×10^{-7}(m^2))

(use of $\rho = \dfrac{AR}{l}$ gives) $\rho = \dfrac{3.32 \times 10^{-7} \times 17.7}{0.25}$ **(1)**

= 2.3×10^{-5} Ω m **(1)** (2.35×10^{-5} Ωm)
(use of R = 18 Ω gives $\rho = 2.4 \times 10^{-5}$ Ω m)
(allow C.E. for value of R from (i) and value of A)

5

[9]

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

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

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

explanation of ρ decreasing **(1)**

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

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

max 4

[10]

25 (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]

26 (a) adequate scale **(1)**
points plotted correctly **(1)**
best fit line (at least a point to right and left of line) **(1)**

3

(b) use of triangle for at least half line **(1)**

gradient $\left(=\frac{11.6}{208}\right)$ = 0.056 ± 0.004 (°C / s) **(1)**

2

(c) $(P = \frac{Q}{t} = \frac{mc\Delta T}{t})$ gives 48 = c × (1.0) × 0.056 **(1)**

c = 860 ± 60 J kg^{-1}K^{-1} (or J kg^{-1} °C^{-1}) **(1)**

2

(d) (use of $E_{th} = ml$ gives) 48 × 200 = 32 ×10^{-3} × l **(1)**
l = 3.0 × 10^{5} J kg^{-1} **(1)**
sensible assumption, e.g. no heat lost to surroundings or temperature does not change or heat is transferred to ice **(1)**

3

[10]

27 (a) (i) graph:

scales (points spread over at least half graph paper, each) **(1)**
correct points (plotted within ½ square) **(1)**
best fit line (if origin shown, line must pass through it) **(1)**

E_k at 350 K = 7.22 × 10^{-21}J (accept 7.23 to 7.27) **(1)**

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

= 2.07 × 10^{-23}(JK^{-1}) (accept 2.00 to 2.15)

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

k = ($\dfrac{2 \times 2.07 \times 10^{-23}}{3}$) = 1.38 ×$10^{-23}$ **(1)** J K^{-1} **(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]

28 (a) (i) pressure **(1)**

(ii) (average) kinetic energy
[or rms speed] **(1)**

(2)

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

$n = \dfrac{1.0 \times 10^{-2} \times 300 \times 10^{3}}{8.31 \times 290}$ **(1)**

= 1.20 (mol) **(1)** (1.24 mol)

(ii) mass of air = 1.24 × 29 × 10^{-3} = 0.036 kg **(1)**
(allow e.c.f from(i))

(iii) $\rho = \dfrac{0.0360}{1 \times 10^{-2}} = 3.6 \text{ kg m}^{-3}$ (allow e.c.f. from (ii))

(5)

(c) (i) same **(1)**
because the temperature is the same **(1)**

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

(ii) different **(1)**
because the mass of the molecules are different **(1)**

(4)

[11]

29 (a) momentum before collision = momentum after collision **(1)**
provided no external force acts **(1)**

(2)

(b) (i) $p = mv$ **(1)**

$10 \times 10^{-3} \times 200 = 2.(0)$ **(1)** kg m s^{-1} (N s) **(1)**

(ii) total mass after collision = 0.40 kg **(1)**
$0.40v = 2.0$ gives $v = 5.(0)$ m s^{-1} **(1)** (allow e.c.f. from (i))

(4)

(c) (i) kinetic energy = $\frac{1}{2}mv^2$

$$\frac{10 \times 10^{-3} \times 200^2}{2}$$ **(1)** (= 200 J)

(ii) kinetic energy = $\dfrac{0.40 \times 5.0^2}{2}$ **(1)** (= 5.0 J)

(iii) $\Delta Q = 200 - 5 = 195$ (J) $= mc\Delta\theta$ **(1)**

$\Delta\theta = \dfrac{195}{10 \times 10^{-3} \times 250} = 78$ K **(1)** (allow e.c.f. for incorrect ΔQ)

(5)

(d) kinetic energy lost (= potential energy gained) = mgh **(1)**

$h = \dfrac{5}{0.40 \times 9.8}$ 1.3 m **(1)**

(2)

[13]

30 (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 = $\frac{3}{2}kT$

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

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

(6)

[10]