Thermal physics

Q1.

(a) Explain what is meant by specific latent heat of fusion.

____

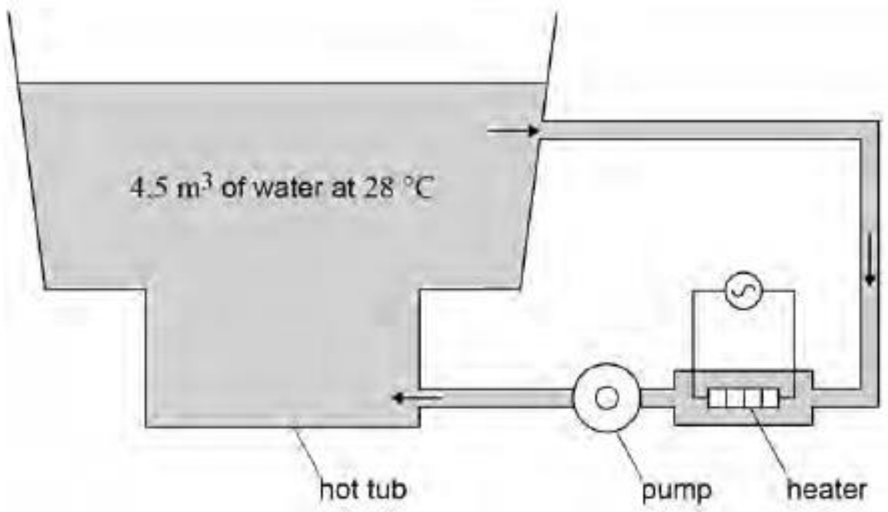
____

____

____

(2)

(b) The diagram shows how the temperature of the water is maintained in a hot tub.



The hot tub system has a volume of 4.5 m^3 and is filled with water at a temperature of 28 °C

The heater transfers thermal energy to the water at a rate of 2.7 kW while a pump circulates the water.

Assume that no heat is transferred to the surroundings.

Calculate the rise in water temperature that the heater could produce in 1.0 hour.

density of water = 1000 kg m^{-3}
specific heat capacity of water = 4200 J kg^{-1} K^{-1}

temperature rise = ____________________ K

(3)

(c) The pump can circulate the water at different speeds.
When working at higher speeds the rise in temperature is greater.

Explain why.
Again assume that no heat is transferred to the surroundings.

___

___

___

___

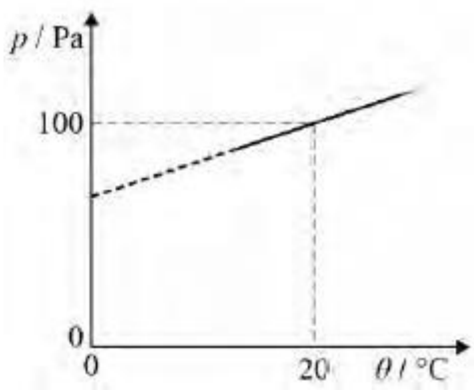
___

(2)
(Total 7 marks)

Q2.

The graph shows the variation of pressure p with temperature θ for a fixed mass of an ideal gas at constant volume.

What is the gradient of the graph?



A 0.341 ⬭

B 0.395 ⬭

C 2.93 ⬭

D 5.00 ⬭

(Total 1 mark)

Q3.

Two flasks **X** and **Y** are filled with an ideal gas and are connected by a tube of negligible volume compared to that of the flasks. The volume of **X** is twice the volume of **Y**.
X is held at a temperature of 150 K and **Y** is held at a temperature of 300 K

What is the ratio $\frac{\text{mass of gas in X}}{\text{mass of gas in Y}}$?

A 0.125

B 0.25

C 4

D 8

(Total 1 mark)

Q4.

The average mass of an air molecule is 4.8×10^{-26} kg

What is the mean square speed of an air molecule at 750 K?

A 3.3×10^{5} m^{2} s^{-2}

B 4.3×10^{5} m^{2} s^{-2}

C 6.5×10^{5} m^{2} s^{-2}

D 8.7×10^{5} m^{2} s^{-2}

(Total 1 mark)

Q5.

A transparent illuminated box contains small smoke particles and air.
The smoke particles are observed to move randomly when viewed through a microscope.

What is the cause of this observation of Brownian motion?

A Smoke particles gaining kinetic energy by the absorption of light.

B Collisions between smoke particles and air molecules.

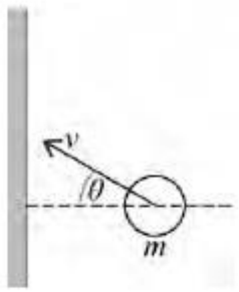
C Smoke particles moving in convection currents caused by the air being heated by the light.

D The smoke particles moving randomly due to their temperature.

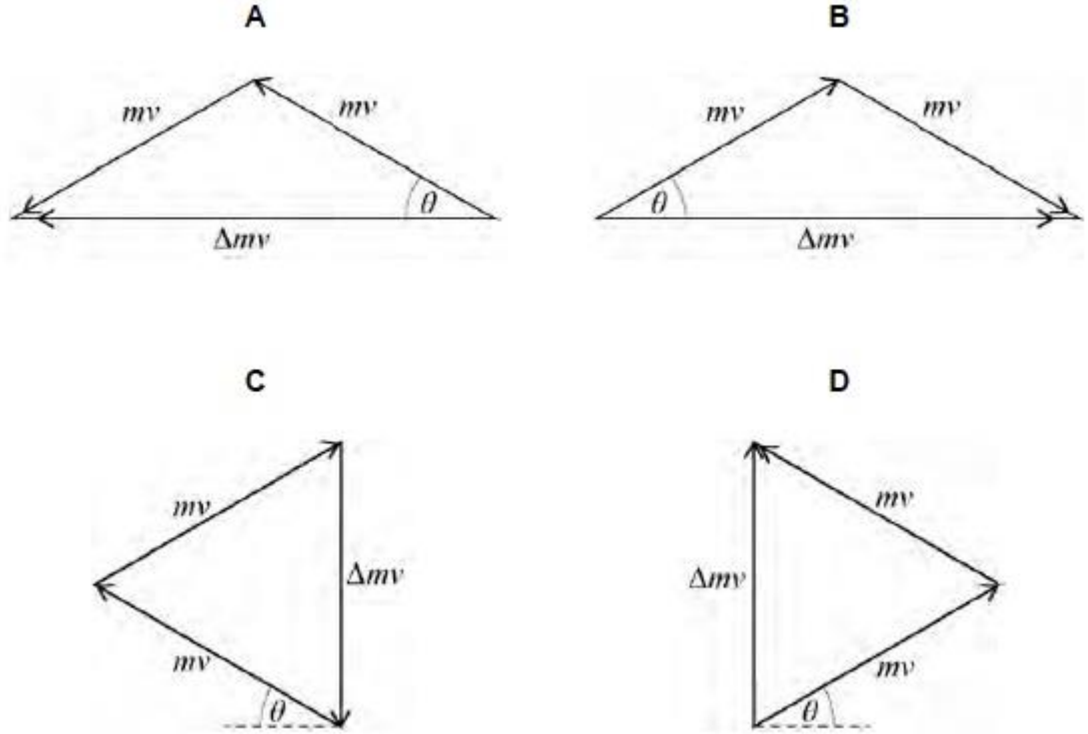
(Total 1 mark)

Q6.

The diagram shows a gas particle about to collide elastically with a wall.



Which diagram shows the correct change in momentum Δ*mv* that occurs during the collision?



A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

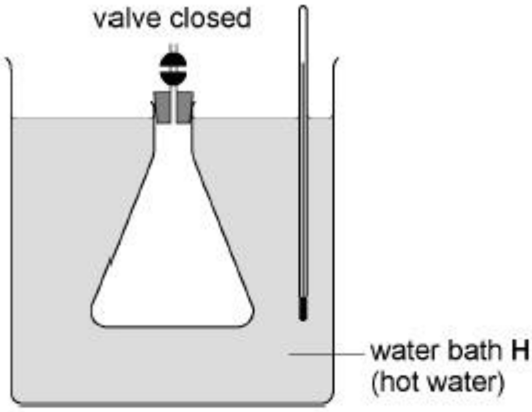
Q7.

This question is about an experiment to estimate absolute zero.

Figures 1a to 1d show the stages in the procedure carried out by a student.

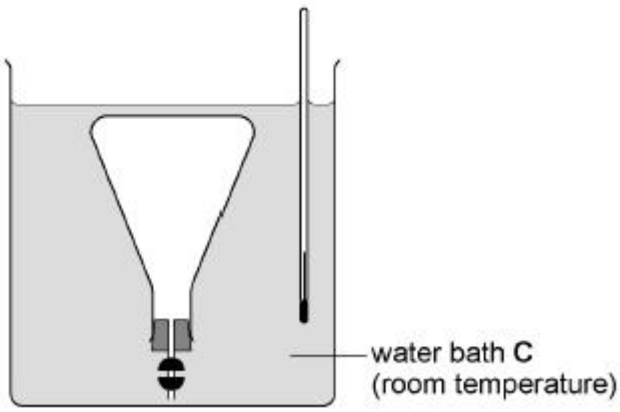
An empty flask fitted with a tube and an open valve is placed in water bath **H** containing hot water. The air inside the flask is allowed to come into thermal equilibrium with the water.
The valve is then closed, trapping a certain volume of air, as shown in **Figure 1a**.

Figure 1a



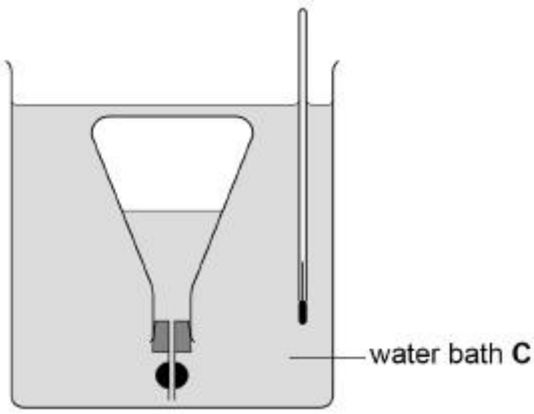
The flask is inverted and placed in water bath **C** in which the water is at room temperature.
The air inside the flask is again allowed to come into thermal equilibrium with the water, as shown in **Figure 1b**.

Figure 1b



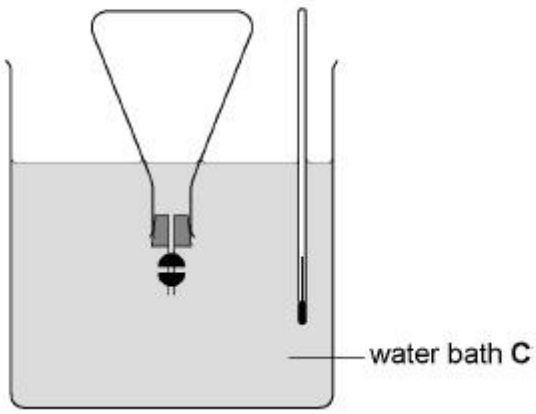
The valve is opened and some water enters the flask, as shown in **Figure 1c**.

Figure 1c



The depth of the inverted flask is adjusted until the level of water inside the flask is the same as the level in the water bath.
The valve is then closed, trapping the air and the water inside the flask, as shown in **Figure 1d**.

Figure 1d



(a) Explain why the volume of the air in the flask in **Figure 1c** is less than the volume of the air in the flask in **Figure 1d**.

____

____

____

____

(2)

(b) Explain why Charles's Law can be applied to compare the air in the flask in **Figure 1a** with the air in the flask in **Figure 1d**.

____

____

____

____

(2)

(c) The flask is removed from water bath **C** and the valve and stopper are removed.

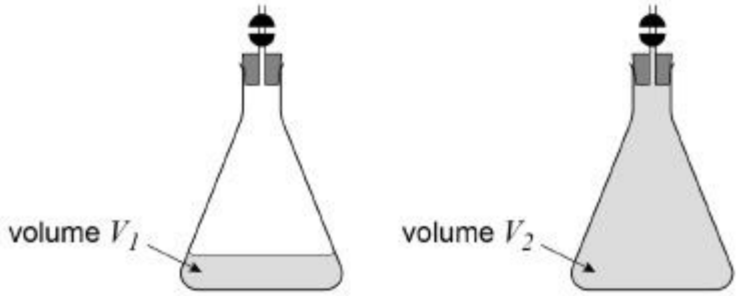
The volume of the water in the flask is V_1

The flask is then completely refilled with water and the valve and stopper replaced.

The volume of the water now in the flask is V_2

The volumes V_1 and V_2 are shown by the shaded parts in **Figure 2**.

Figure 2



Explain how V_1 and V_2 can be determined.

In your answer you should

- identify a suitable measuring instrument
- explain a suitable procedure to eliminate possible systematic error.

(3)

(d) Plot on **Figure 3** points to show the volume V and the temperature θ of the air in the flask when

- the flask is as shown in **Figure 1a**
- the flask is as shown in **Figure 1d**.

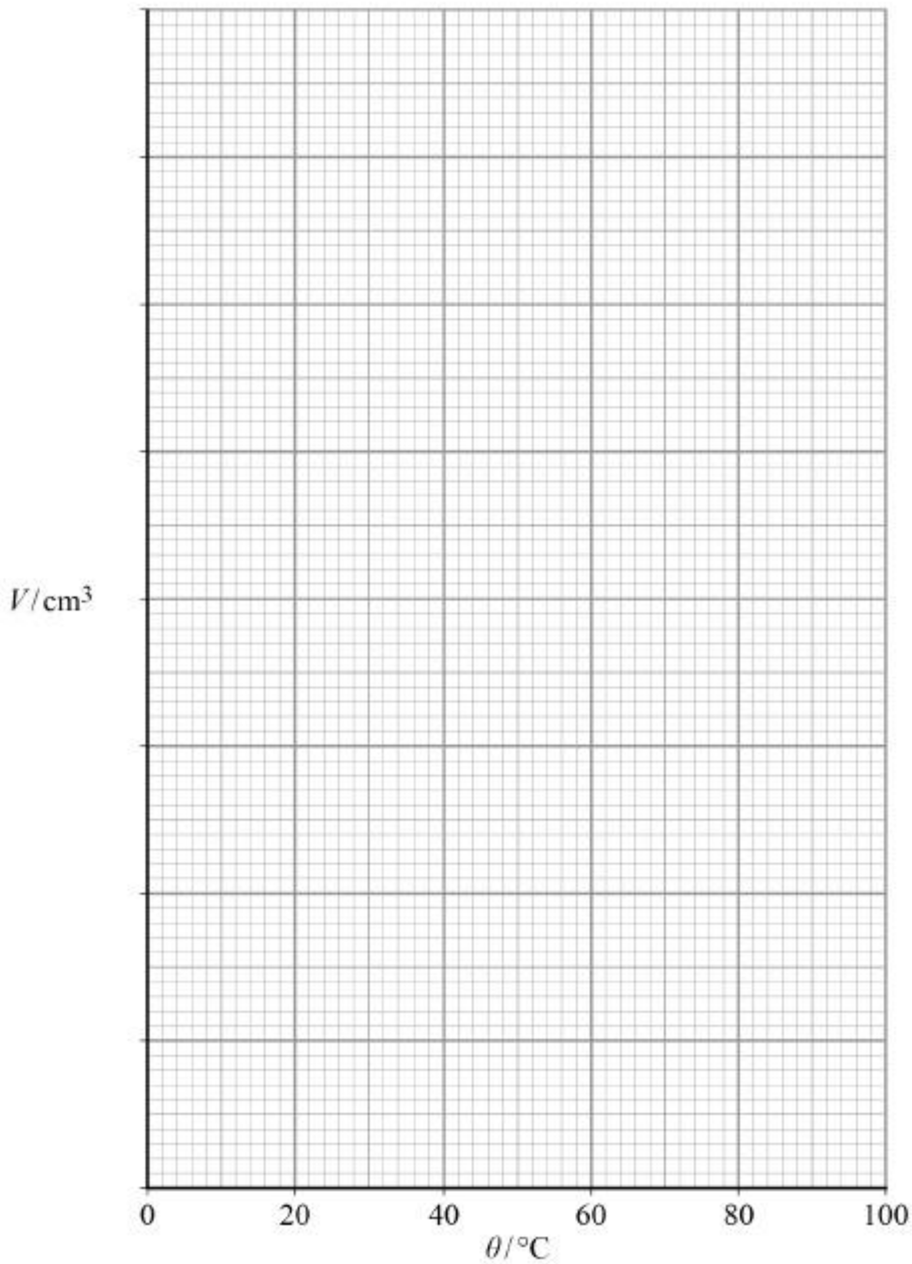
The temperature of the hot water bath is 86 °C

Room temperature is 19 °C

V_1 = 48 cm^3

V_2 = 255 cm^3

Figure 3



(3)

(e) Add a best fit line to your graph in **Figure 3** to show how V should vary with θ according to Charles's Law.

(1)

(f) Determine the value of absolute zero in °C using your graph in **Figure 3**.

value of absolute zero = ____________________ °C

(3)

(Total 14 marks)

Q8.

A continuous stream of water falls through a vertical distance of 100 m.
Assume no thermal energy is transferred to the surroundings.
The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

What is the temperature difference of the water between the top and bottom of the waterfall?

A 0.023 K ☐

B 0.23 K ☐

C 2.3 K ☐

D 4.3 K ☐

(Total 1 mark)

Q9.

A student measures the power of a microwave oven. He places 200 g of water at 23 °C into the microwave and heats it on full power for 1 minute. When he removes it, the temperature of the water is 79 °C.

The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

What is the average rate at which thermal energy is gained by the water?

A 780 W ☐

B 840 W ☐

C 1.1 kW ☐

D 4.6 kW ☐

(Total 1 mark)

Q10.

An ice cube of mass 0.010 kg at a temperature of 0 °C is dropped into a cup containing 0.10 kg of water at a temperature of 15 °C.

What is the maximum estimated change in temperature of the contents of the cup?

specific heat capacity of water = 4200 J kg^{-1} K^{-1}
specific latent heat of fusion of ice = 3.4×10^5 J kg^{-1}

A 1.5 K ☐

B 8.7 K ☐

C 13.5 K ☐

D 15.0 K ☐

(Total 1 mark)

Q11.

Specimens **P** and **Q** of the same gas exert the same pressure. **P** is at a temperature of 280 K and contains 10^{20} molecules per unit volume. The temperature of **Q** is 350 K.

What is the number of molecules per unit volume in **Q**?

A 0.09×10^{20} ☐

B 0.75×10^{20} ☐

C 0.80×10^{20} ☐

D 1.25×10^{20} ☐

(Total 1 mark)

Q12.

Which of the following is **not** used as valid assumption when deriving the equation

$P = \frac{1}{3} Nm (c_{rms})^2$ in the simple kinetic theory of gases?

A The molecules suffer negligible change of momentum on collision with the walls of the container. ☐

B Attractive forces between molecules are negligible. ☐

C The duration of a collision is negligible compared with the time between collisions. ☐

D The volume of the molecules is negligible compared with the volume of the gas. ☐

(Total 1 mark)

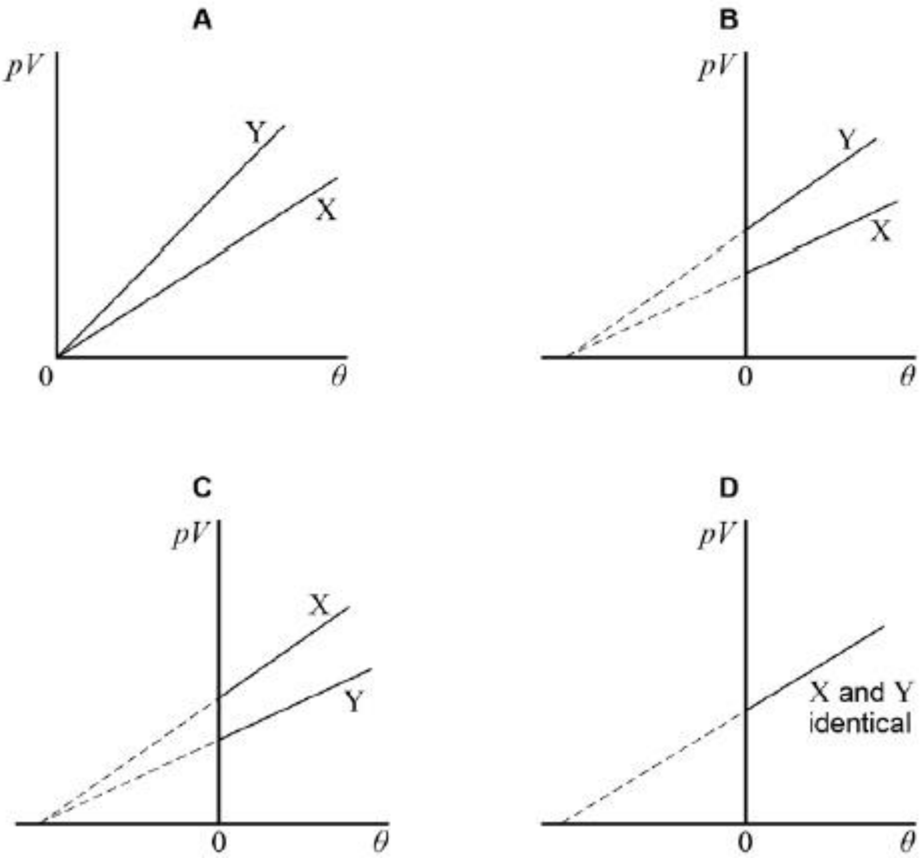
Q13.

One mole of gas occupies a volume V at a pressure p and Celsius temperature θ.

The graphs, **A** to **D**, show variation of pV with θ.
Line X is for one mole of nitrogen and line Y is for one mole of oxygen.

Relative molecular mass of nitrogen = 28
Relative molecular mass of oxygen = 32

Which graph is correct?



A ☐

B ☐

C ☐

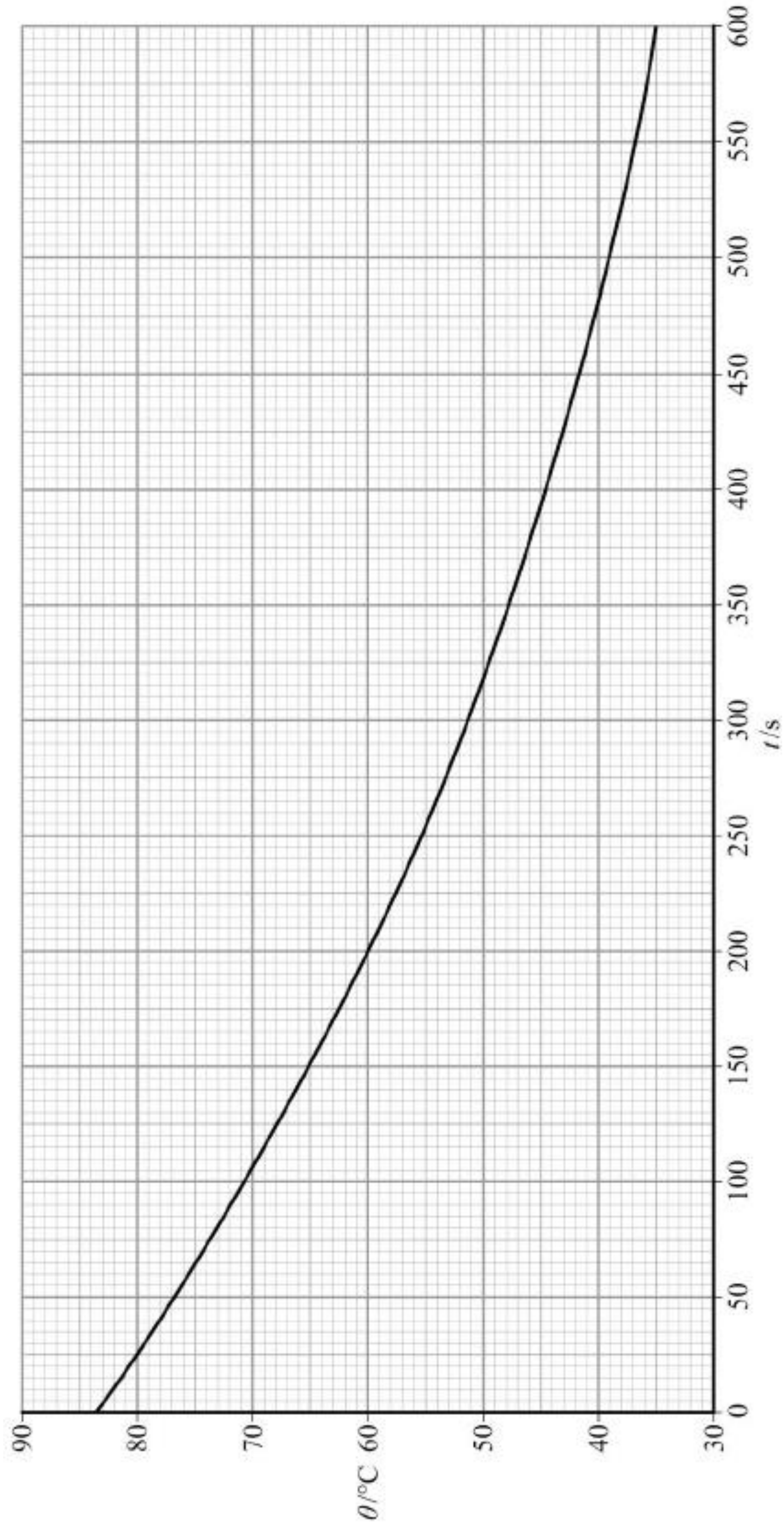
D ☐

(Total 1 mark)

Q14.

A temperature sensor is connected to a data logger to monitor how the temperature θ of a fixed mass of recently−boiled water varies with time *t*, over an interval of 600 s. These data are processed to produce the graph shown in **Figure 1**.

Figure 1



(a) Determine the temperature θ_1 of the water when t is 190 s.

θ_1 = ____________________ °C

(1)

(b) Determine the gradient G_1 of the graph at t is 190 s.

G_1 ________________________

(3)

(c) When t = 370 s the temperature θ_2 = 46.6 °C and the gradient G_2 = − 0.0645.

The room temperature θ_R is given by $\dfrac{G_1\theta_2 - G_2\theta_1}{G_1 - G_2}$

Evaluate θ_R.

θ_R = ____________________ °C

(1)

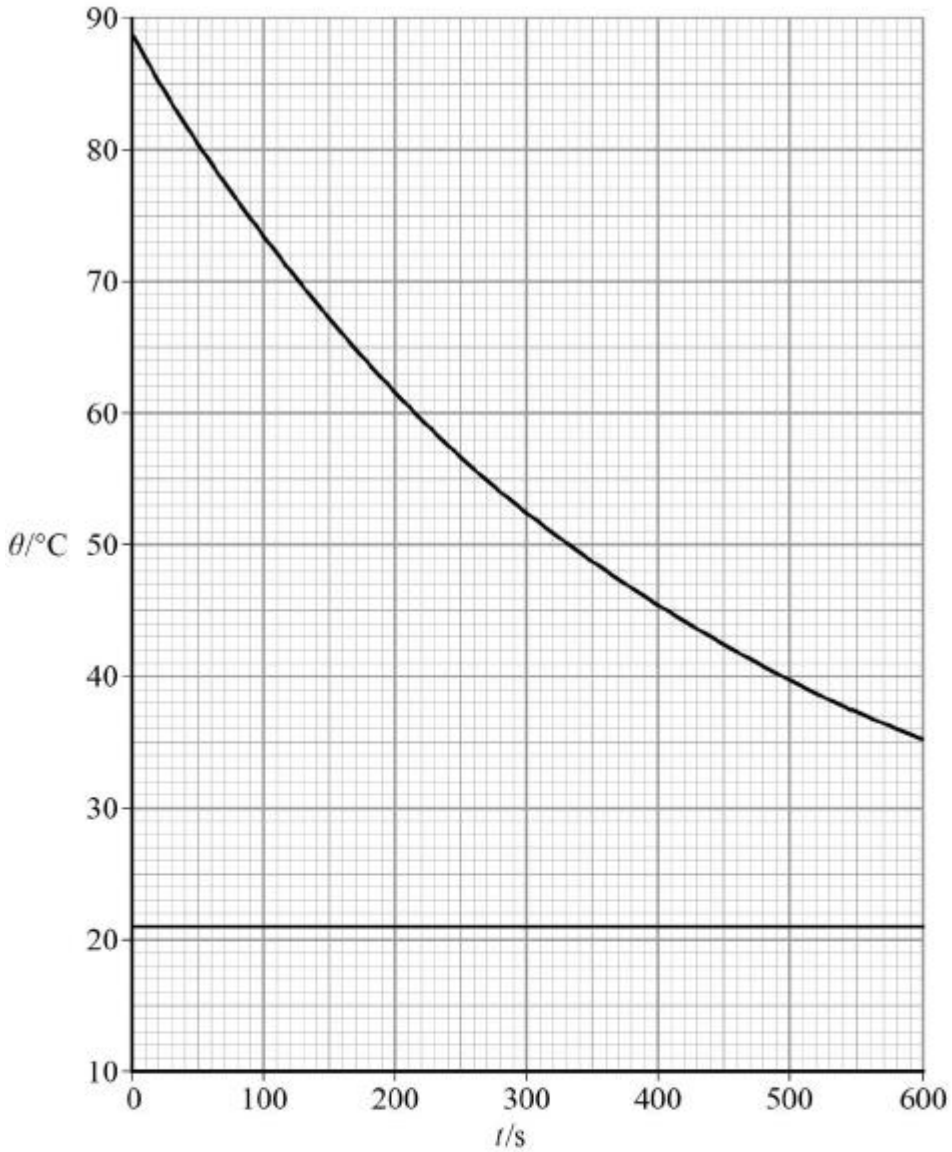
(d) It can be shown that when a hot object at a temperature θ is allowed to cool in a draught, the rate at which the temperature decreases is directly proportional to the temperature difference ($\theta - \theta_R$) between the object and the surroundings.

A student realises that ($\theta - \theta_R$) will decrease exponentially with time and designs an experiment in which two temperature sensors are connected to a data logger.

- Sensor 1 is placed in a beaker of recently−boiled water.
- Sensor 2 measures the air temperature in the room.
- The data logger is programmed to record the output from the sensors as the water cools for 600 s.

The output data from the sensors are processed to produce the graph shown in **Figure 2**.

Figure 2



$(\theta - \theta_R)$ will decrease exponentially in the same way that the potential difference (pd) across a discharging capacitor decreases with time.

When a capacitor discharges, the pd across the capacitor falls to $\frac{1}{e}$ of an initial value in a time called the **time constant**. Electronic engineers assume that a capacitor becomes fully discharged in a time equal to **5 time constants**.

Estimate the time taken for the water to cool down to room temperature.

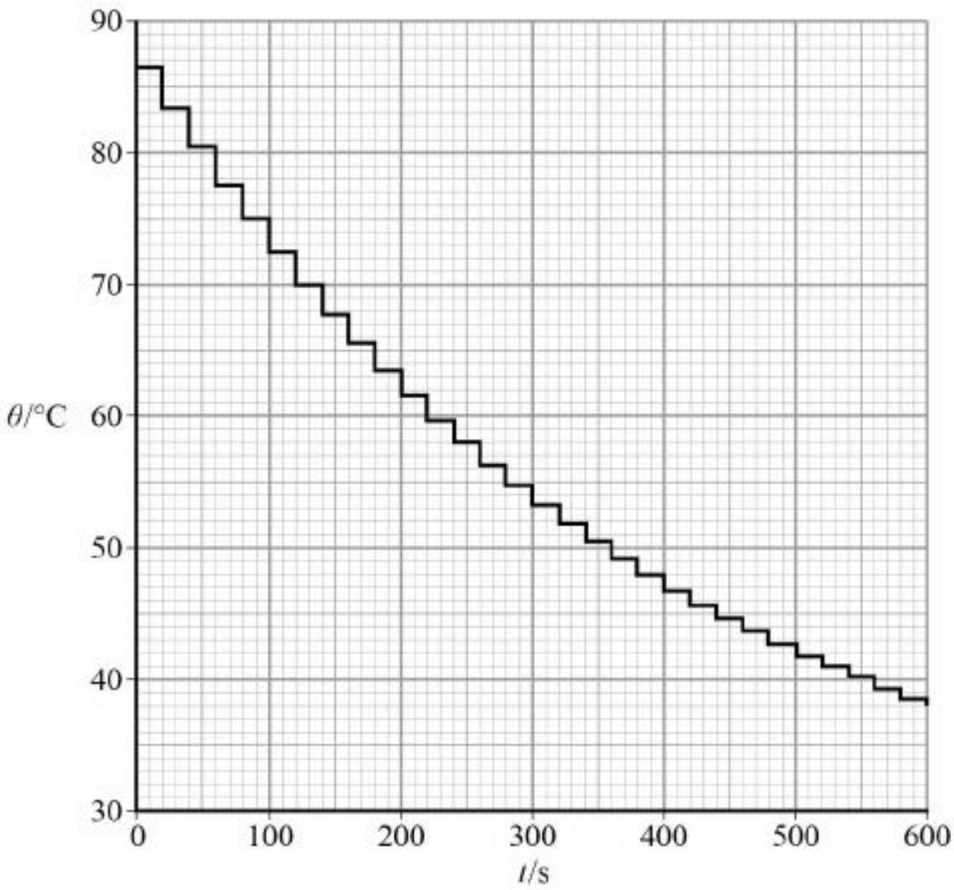
time taken = ____________________ s

(4)

(e) Another student carries out the experiment using the same mass of recently−boiled water and beaker as before.

The output data for sensor 1 from this student's experiment are shown in **Figure 3**.

Figure 3



Account for the differences between these results and the way they are displayed, with those shown in **Figure 2**.

You should include appropriate quantitative detail in your answer.

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

(5)

(Total 14 marks)

Q20.

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

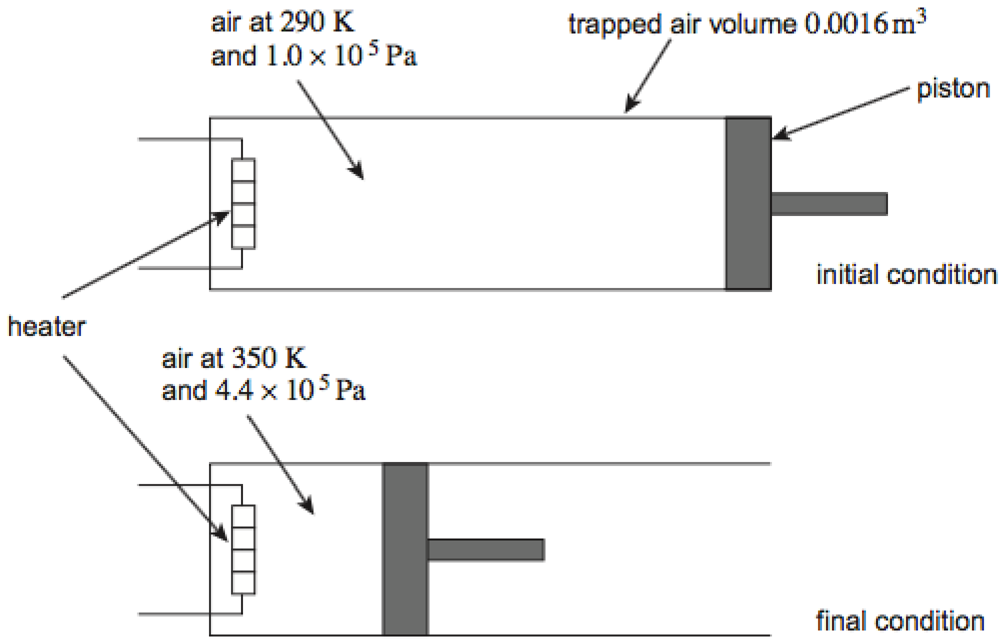
State **two** conditions necessary to complete the statement.

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.

____

____

____

____

____

____

____

(2)

(Total 9 marks)

Q21.

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

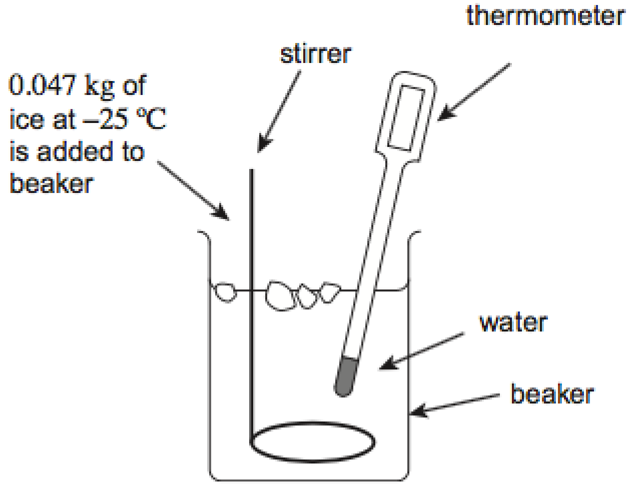
Place a tick (✓) in the right-hand column to show the correct answer.

	✓ 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 = __________

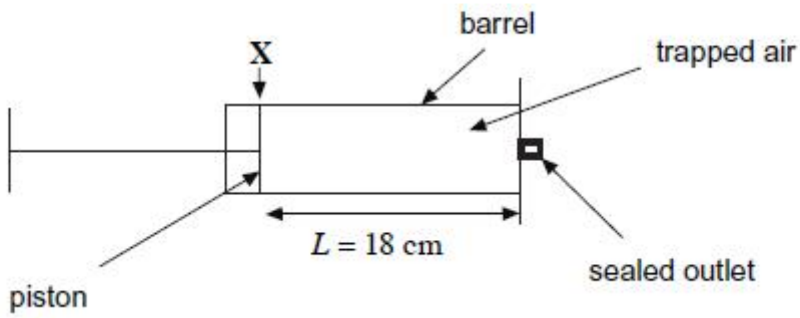
(2)

(Total 5 marks)

Q22.

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.

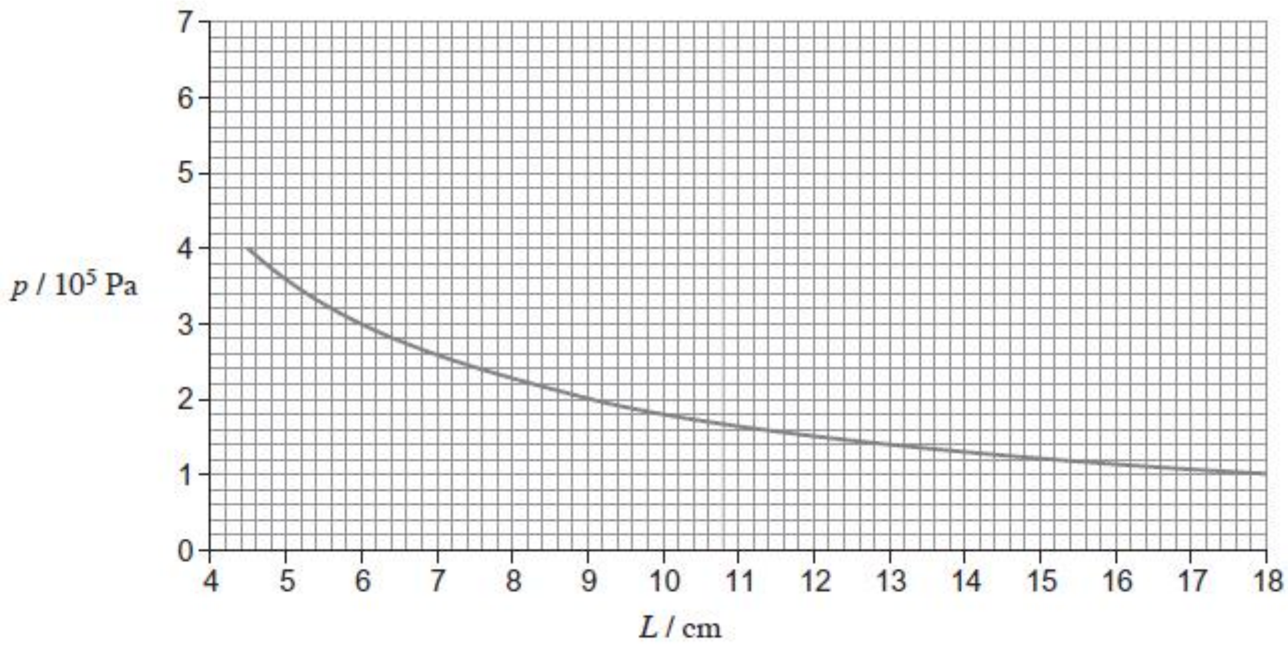
mean square speed ____________________ unit __________

(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.

____

____

____

____

____

____

____

____

(4)

(Total 22 marks)

Q23.

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

Explain what is meant by this statement.

___

___

___

___

(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)

Q24.

(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)

Q1.

(a) Specific latent heat of fusion is the <u>energy</u> (required) to change 1 kg / unit mass of material from the solid state to the liquid state or melt/fuse ✓

Without a change of temperature or at the freezing/melting temperature/point ✓

The direction of energy transfer must be consistent with the direction of the change of state (If energy to change… is given then required or needed is implied)

2nd mark stands alone.

2

(b) (Dividing both sides of the equation $\Delta Q = m\,c\,\Delta\theta$ by Δt gives $\Delta Q/\Delta t = m\,c\,\Delta\theta/\Delta t$ or

$\Delta\theta = (\Delta Q/\Delta t) \times \Delta t/m\,c$ where $m = \rho V$)

$\Delta\theta = 2700 \times (60 \times 60) / (4.5 \times 1000 \times 4200)$ ✓

Full substitution correct ✓

Temperature rise = $\Delta\theta$ = 0.51 (K) ✓ (= 0.514 K)

Working <u>must be seen</u> as there is a self-cancelling error with two 1000 factors.

So answer alone gains the 3rd mark only.

First mark can be gained if (60 × 60) is absent even if not re-arranged.

The change of temperature may be written as a difference between 28 °C and an unknown temperature (allow in kelvin written either way round ie with incorrect sign)

*1 sig fig is **not** acceptable.*

Useful numbers:

$4.5 \times 1000 \times 4200 = 1.89 \times 10^{7}$

$2700/(4500 \times 4200) = 1.4 \times 10^{-4}$

Max 2 if:

Omits (60 × 60) giving 1.43×10^{-4} K

Omits 60 giving 8.57×10^{-3}

3

(c) (When the pump is working at speed) the pump is <u>doing work</u> (on the water) ✓

Work (and heat both) can raise the temperature of a body (as stated in the 1st Law of thermodynamics) (this may be expressed as work is converted to thermal energy) OWTTE

OR

The pump increases the randomness / turbulence of the water/molecules

OR

The <u>mean</u> square speed/*mean* kinetic energy is proportional to the (absolute)

temperature ✓
(this may be given in the form on an equation) OWTTE

(Lenient mark – a reference to random motion or more collisions may gain this mark but a simple increase in kinetic energy is not enough).

Do not penalise answers that go nowhere unless they directly contradict a marked answer.

2

[7]

Q2.

A

[1]

Q3.

C

[1]

Q4.

C

[1]

Q5.

B

[1]

Q6.

B

[1]

Q7.

(a) pressure (of air) in **Figure 1c** is greater than (pressure of air) in **Figure 1d**

OR

pressure in **Figure 1d** is lower than pressure in **Figure 1c** $_1$✓

(since) temperature is the same

OR

Boyle's Law applies

OR

PV = constant; $_2$✓

any suggestion that pressure is constant **OR** the volume is constant **OR** the temperature changes **OR** the amount of air in the flask increases as flask is raised loses both marks

for ₁✓ must refer to either of the relevant figures or give other detail, eg 'when flask is lifted' so their meaning is unambiguous;

*allow 'when volume decreases pressure increases' but must be comparing **1c** with **1d***

*allow 'water pressure decreased in **1d**'*

*treat 'air was compressed' (in **1c**) as neutral*

*reject 'pressure released (in **1d**)'*

for ₂✓ allow mean KE of molecules is the same

accept $P \propto \frac{1}{V}$ *;*

allow nRT = constant;

reject PV = k (unless k = constant is also seen)

2

(b) same (air) pressure ₁✓

same mass of air ₂✓

any suggestion that temperature is constant **OR** that volume is constant **OR** that pressure has changed **OR** the amount of air in the flask decreases as flask is moved from H to C loses both marks

for ₁✓ and ₂✓ accept constant/unchanged = same and condone 'assume same pressure/mass of gas'

for ₂✓accept same (number of) moles or same amount of gas

no credit for stating 'volume increases as temperature increases'

'temperature is in equilibrium' is neutral

2

(c) relevant quantity and instrument seen:

volume(s) (of liquid) measured using a <u>measuring cylinder</u> **OR** graduated beaker ₁✓

reject 'measuring beaker' and 'burette'

eye level <u>with the bottom</u> of the meniscus (allow suitable sketch showing eye) ₂✓

'measure at eye level' **OR** 'eye level with graduation' **OR** 'eye perpendicular to graduation' are not enough to avoid <u>parallax</u> error ₃✓

see alternative opposite; if both approaches are given record the mark to whichever scores most

alternative

for ₁✓mass (of liquid/flask) measured using a <u>balance</u>

reject 'scales' and reject 'weigh/find weight/weigh the mass'

*for ₂✓valid method to account for the mass of flask eg tare/zero balance (ECF 'scales') with (same) empty flask on balance and then measure mass of flask with liquid **OR***

<u>subtract</u> mass of empty flask from mass of flask containing liquid; don't penalise 'weigh' twice ***OR***

ensure the balance is on a horizontal surface for ₃✓find volume(s) using $V = \frac{m}{\rho}$ *; V must be subject*

3

(d) suitable vertical scale for their data points covering at least half the grid;

false origin on the vertical scale correctly marked;

vertical scale marked at sensible intervals, based around intervals of 1, 2, 4 or 5 etc; graduations no further than 2 major divisions apart $_1$✓

19, 207 plotted to nearest ½ grid square $_2$✓

86, 255 plotted to nearest ½ grid square $_3$✓

for $_1$✓the two correct data points a suitable scale is 10 cm^3 *for each major division*

an unmarked origin is be assumed to be (0, 0); if a broken scale symbol is not used and the V scale becomes non-linear, withhold the mark

award $_{23}$✓= 1 MAX for thick or poorly-marked points eg thicker than half a grid square;

reject blobs, dots and circles

3

(e) **continuous ruled** best-fit line of <u>positive</u> gradient through intersection of cross-hairs of their points ✓

apply same criteria for judging line quality as in part (c); don't penalise thick line if thick points are penalised in part (d)

1

(f) legitimate method to <u>calculate</u> horizontal intercept

eg gradient calculated from ΔV divided by $\Delta\theta$ ie numerical evidence of 2 steps required; don't penalise read off errors or small steps

reads (to within 1 grid square) **OR** uses a point on the line to calculate (with correct use of $y = mx + c$) the vertical intercept; sensible values are shown on the right $_1$✓

correct use of their vertical intercept and their gradient to calculate the horizontal intercept using –1 × vertical intercept divided by gradient $_2$✓

OR

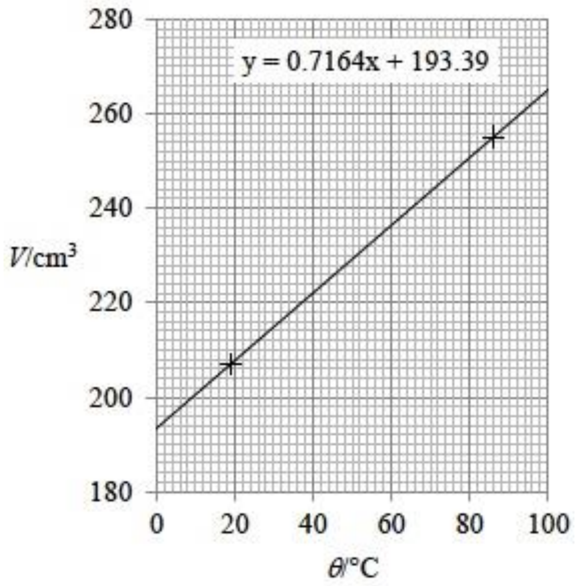
similar triangles, eg

$\frac{255-207}{86-19} = \frac{207-0}{19-\theta}$ or similar seen $_1$✓

minimum $\Delta\theta$ = 86 – 19 (= 67as in example above) $_2$✓

result in range –260°C to –285°C $_3$✓

withhold mark for missing sign; no credit for unsupported answer



in $_1$✓ condone V changed to m^3 when calculating gradient and finding intercept values

for a graph with a negative gradient allow credit for $_1$✓ only = 1 MAX

no credit for non-linear graph = 0 MAX

data which may be seen in working include

V = 193 cm^3, θ = 0 °C; V = 265 cm^3, θ = 100 °C;

V = 207 cm^3, θ = 19 °C; V = 255 cm^3, θ = 86° C

3

[14]

Q8.

B

[1]

Q9.

A

[1]

Q10.

B

[1]

Q11.

C

[1]

Q12.

A

[1]

Q13.

D

[1]

Q14.

(a) θ_1 = 61.0 ± 0.5 °C ✓

reject 2 sf θ_1

1

(b) sensible tangent drawn at *t* = 190 s; correct read-offs for points (± 1 mm) from triangle with step sizes at least 8 × 8_1 ✓

$G_1 = -9.57 \times 10^{-2}$ $_3$✓

for $_3$✓ insist on correct sign and POT; accept result in range 1.05×10^{-1} to -9.0×10^{-2}

3

(c) substitution correct leading to θ_R = 17.3 ± 2.0 °C ✓

allow ECF

1

(d) $\theta_0 - \theta_R$ correctly evaluated to ± 1 °C for θ_0 at suitable reference time $_1$ ✓

evaluates $\frac{\theta_0 - \theta_R}{e}$ $_2$✓

evaluates θ from $\frac{\theta_0 - \theta_R}{e}$ + θ_0 ; time constant deduced from graph with evidence of working (read offs to both axes are required) $_3$✓

time for object to reach room temperature in range 1900 to 2000 s $_4$✓

example for $_1$✓: θ_0 = 89 °C at t = 0 gives $\theta_0 - \theta_R$ = 89 − 21 = 68 °C

allow ecf for failure to take account of θ_R in $_1$ ✓

example for $_2$✓: $\frac{\theta_0 - \theta_R}{e} = \frac{68}{2.718} = 25$; allow ecf for failure to take account of θ_R in $_1$✓

example for $_3$✓: θ = 25 + 21 = 46; time constant = 390 s

example for $_4$✓: time to reach room temperature = 5 × 390 = 1950 s; no ecf for errors in $_1$✓ or in $_3$✓

4

(e) the starting temperature was lower $_1$✓

the starting temperature was 86.5 °C compared to 89.0 °C $_2$✓

the room temperature was higher 3✓

the draught was less 4✓

the water had only cooled to 38.0 °C after 600 s 5✓

the sample rate of the data logger was lower 6✓

samples were recorded every 20 s (rate for original experiment was much higher) 7✓

other approaches are possible

allow ± 0.3 °C for any temperature quoted for 2✓or for 5✓

MAX 5

[14]

Q20.

(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 × 8.31 × 350 / (4.4 × 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 × 10^5 × 0.0016 / (8.31 × 290) = 0.066 (mol) ✓ (0.0664)

or

= 4.4 × 10^5 × 0.00044 / (8.31 × 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 × 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]

Q21.

(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]

Q22.

(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)
/ $V = \pi r^2$ 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

$p = \frac{\frac{1}{3} N m \overline{c^2}}{\pi r2 L}$ *or equivalent*

must be correct equation with V in terms of L

with p as subject

4

[22]

Q23.

(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 × 130 × (327.5 – 21) + 0.75 × 23000 ✓
(= 29884 + 17250)
= 47134 ✓
= 4.7×10^4 (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]

Q24.

(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]

Q1.

(a) Most students seemed to be completely aware of what was being asked but their answers commonly fell short because of missing details. Less than half referred to the absence of a change in temperature and many also missed stating which change of state was occurring and that a unit mass was involved.

(b) A majority performed this calculation well and with a good degree of clarity (64.5% of students scored all three marks). One error made by normally competent students was to give the final temperature rather than the rise in temperature. The other and more common fault was to quote an answer to only one significant figure. Only the very weak students made faults in re-arranging the equations.

(c) It was a common misconception that the time it took for the water to pass the heater had an effect on the average rise in temperature. This could have been a possibility if the question had not said that heat was not lost to the surroundings. The other error seen was for students to relate kinetic energy of the whole body of water to the temperature. It is the mean kinetic energy of the random motion of molecules that is related to temperature. In addition, very few students picked up on the idea that work done, as well as heating, can raise the temperature. Nearly three-quarters of students failed to score.

Q2.

43.8% correct

Q3.

61.7% correct

Q4.

77.6% correct

Q5.

73.6% correct

Q6.

15.0% correct

Q7.

This question addressed some of the ideas behind required practical activity 8.

(a) Many students stated that the volume of air in 9c was less because water had entered the flask, but the better students realised that the expected response was that the pressure of the air had increased. Only 16% qualified their answer by adding that the temperature was the same for the situations in 9c and 9d, or that Boyle's Law could be applied. Some disqualified themselves by stating that air entered the flask as it was raised. Knowledge of the gas laws seemed generally patchy, with only approximately 40% of students making progress with this question or with 03.2.

(b) Many answers suggested that Charles's Law was even less well understood than Boyle's Law. Only the better students realised that they were being asked to give two conditions that should be met if Charles's Law is to apply. While some correctly stated that pressure must remain the same, only 7% added that the mass of gas must be constant.

(c) The direct and the indirect approaches to finding the volumes proved equally popular, but a small minority of students tried unsuccessfully to use some variant of the gas laws. Examiners expected a measuring cylinder to be used for the direct method and wanted students to explain that the reading was taken with the eye level with the bottom of the meniscus to avoid parallax error. Very few could give a completely correct response. For the indirect approach, examiners gave no credit for 'scales' rather than 'balance' (the instrument had been clearly identified in question 1) and rejected the idea that mass could be 'weighed'. However, many students gave a sensible way to account for the mass of the flask when determining the mass of water and could explain how the volume was obtained, as the density was known. Examiners did not allow "1 g = 1 cm3", variants of which were seen rather too frequently. As with question 01.6, students frequently wrote more than they needed to, yet the number scoring all three marks (5.1%) was disappointing.

(d) Many students plotted (19, 48) which probably saved the graph scaling mark but ruined their chances of earning full credit in question 03.6. Those plotting the correct (19, 207) and (86, 255) often chose to include the origin, compressing the scale. A minority plotted (19, 255) and (86, 48), producing a graph with a negative gradient. Nearly 60% of the students scored at least two marks.

(e) The lines drawn were of mixed quality. Unfortunately, some students forced the line through the origin. Examiners expected the line to pass through both plotted points, yet over 40% of students were unable to score.

(f) The work here was sometimes very good and usually easy to follow. Even when the line had been drawn to pass through (19, 207), producing a small positive value for absolute zero, the students tried a logical approach to the problem and duly gained some credit.
Clearly at this point, the students who had produced a graph with a negative gradient should have been asking themselves some serious questions, so it was disappointing to see how few revisited question 03.4 rather than optimistically writing down −273. Students need to be reminded they should inspect their work before moving on. Those who did everything right but omitted the minus sign with their result would be annoyed by their oversight. Over half of the students made some progress and more than 20% obtained full credit.

Q20.

(a) Many students easily gave the correct answers here. Weaker responses combined the question with an ideal gas assumptions question. It was common to see the 'at constant temperature' followed by 'all collisions are assumed to be elastic' or similar. So the constant mass was referred to in a minority of scripts.

(b) (i) The best responses were able to manipulate pV/T=constant for the initial and final states to give the correct final volume for full credit. As more data was available in the question the more circuitous route of employing pV=nkT was also used by some students to gain full credit. Students who correctly set-up either of these approaches but fell short of the accepted final answer due to arithmetical errors were given partial credit. Weaker responses failed to take into account the difference in temperature between the initial and final states and gained no credit due to this physics error.

(ii) This turned out to be easy for some and difficult for others. Some had already tacked the problem by the approach they took to part (b)(i) and simply repeated their work. Some students did run into difficulty because they chose to use the wrong volume or they calculated the number of molecules rather than the number of moles present.

(iii) The density equation was known by almost all students but it was in substituting the data where mistakes were made. The wrong volume was selected by some whilst others could not find the mass of the gas using the molar mass. In fact some thought these masses are identical.

(c) The obvious first marking point that the speed of the molecules increases with increased temperature was known by almost all students. It was interesting to note that many thought that gas molecules vibrate but this point was ignored in the marking. Very few students related the mean kinetic energy to the temperature in an equation or as a proportional relationship. Instead they spent time establishing the link between speed and kinetic energy and ignored the link to temperature.

Q21.

(a) Only about 60% of students gave the correct alternative. Many students thought the energy was used to break all the intermolecular bonds and slightly fewer thought the molecules would vibrate with more kinetic energy.

(b) (i) An easy question where just a few students made slips. Some did so when converting the answer to scientific notation by giving the wrong power of 10. The final answer line takes precedence over calculated answers in the body of the answer space. Others showed incorrect rounding i.e. 15510 J does not round to 15000 J.

(ii) Most students are very comfortable with this section of the specification and performed this calculation easily. There was a sizable group, however, who failed to get the sign correct after rearranging the equation or who simply quoted the 1.8 × 10^4 J as the answer.

(iii) This calculation was done well. Interestingly some students did not use their answer to **b(i)** which they got wrong but started the calculation from scratch which this time they got right. The majority of errors were seen in the unit mark where J kg^{-1} featured frequently. It should be noted here that °K is not accepted as K (Kelvin symbol) and also that C is not accepted as °C.

Q22.

Part (a) (i) was completed correctly by the majority of candidates. Common mistakes seen were not converting L into metres and neglecting to double the radius to obtain the final answer.

Over ¾ of candidates achieved full marks for the calculation in part (a) (ii) with most candidates choosing to use $PV = NkT$ to obtain the answer. A smaller number of candidates used $PV = nRT$ and $N = n\,N_A$; although this method involved slightly more working it was performed correctly.

Part (a) (iv) proved difficult for most candidates; a comparison of volume of the particles and the volume occupied by the gas was made but few could use this to support an assumption of kinetic theory.

The vast majority of candidates correctly carried out the calculation in part (b) but some of these had problems with the unit for mean square speed often quoting this unit as $m\ s^{-1}$. Other candidates misread the question and found the rms speed.

Candidates were familiar with the technique required to analyse data presented in a graph to show proportionality but some candidates lost marks through poor communication of their working.

Part (d) was another explanation type question where candidates had difficulty scoring marks. The question was set in a context which was slightly removed from a standard explanation of the relationship between pressure and volume. Candidates seemed unfamiliar with how to use kinetic theory to explain this relationship. An explanation based on change in force due to change in rate of change of momentum was required to achieve full marks and unfortunately this was lacking from most candidates' answers. When this was attempted many of these candidates stated that the rate of change of momentum had increased due to the particles travelling faster even though the compression had happened at constant temperature.

Q23.

This question was performed well by a majority of students. The explanation of a specific heat capacity in part (a) was very straightforward. The calculation in part (b) was done well by all but the weakest students even though it contained parts dealing with both specific heat capacity and latent heat. It was in choosing an incorrect number of significant figures that students lost the most marks.

Q24.

As in previous questions students found explanations difficult but this time they also found some of the calculations difficult. In part (a), the Quality of Written Communication question, it was surprising to come across so many students who appeared to have no knowledge of any experiment concerning gases. This became apparent when their potential experiment was considered. Some thought it feasible to measure the speed of molecules as the temperature was reduced. Others thought that the temperature would reduce uniformly as the pressure was reduced, even reaching absolute zero. A few latched onto an equation such as specific heat that involved temperature and thought they could substitute measured data when the temperature was equal to zero. These students were not an isolated few. Almost a third tackled the experiment in a way that would not work or be impossible to perform. Even students who used a workable idea thought that the experiment could be continued and actually reach absolute zero. The more able students did find this a straightforward task and gave the necessary details in a logical manner but the majority of students did not give their description in a clear fashion and their answers seemed to change direction many times. A very simple error made by many was to quote the temperature of absolute zero as −273 K. The question about assumptions, part (b)(i) was not read carefully by a number of students. In particular they did not respond to the emboldened 'movement' in the question. So many answers given were from the usual list of assumptions but they were not given credit here. An example being, 'molecules have negligible volume'. Even the stronger students sometimes got caught out in this way. As in previous exams some students mistakenly thought that random motion and Brownian motion are one and the same. The calculation of (b)(ii) was not done well by a majority of students. Not because of poor arithmetic but because students did not understand the processing of the term 'mean square speed'. Some students also had difficulties in part (c) with substituting data into the kinetic ideal gas equation. A large number of students squared the number given in the question for the mean square speed before making the substitution.