



GuideMyGrades

— YOUR GOALS. OUR EXPERTISE. —

EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Thermodynamics (9)

A Level Physics Topic 9

30 questions · 239 marks · Mark schemes included

A Level only content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

 guidemygrades.com

 [@Guidemygrades](https://www.instagram.com/Guidemygrades)

 [@Guidemygrades](https://twitter.com/Guidemygrades)

 [@Guidemygrades](https://www.youtube.com/Guidemygrades)

 info@guidemygrades.com

 Piccadilly Business Centre, Unit C, Aldow Enterprise Park
Blackett Street, Manchester, M12 6AE

HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

QUESTION	SOURCE	MARKS	PAGE
9.1 SPECIFIC HEAT CAPACITY AND SPECIFIC LATENT HEAT		17 Qs · 128 marks	4
1. Q5	A Level Paper 2 June 2017	1	5
2. Q11	A Level Paper 2 June 2017	3	6
3. Q11	A Level Paper 2 October 2020	3	7
4. Q12	A Level Paper 2 November 2021	4	8
5. Q11	A Level Paper 2 June 2019	5	9
6. Q12	A Level Paper 2 June 2023	5	10
7. Q15	A Level Paper 2 June 2022	6	11
8. Q7 <i>also Topic 1</i>	A Level Paper 3 June 2018	7	12
9. Q2 <i>also Topic 1</i>	A Level Paper 3 June 2019	7	14
10. Q3	A Level Paper 3 June 2022	7	16
11. Q14	A Level Paper 2 June 2023	9	17
12. Q3 <i>also Topic 1</i>	A Level Paper 3 June 2023	10	19
13. Q19 <i>also Topic 4</i>	A Level Paper 2 June 2025	10	22
14. Q6 <i>also Topic 1</i>	A Level Paper 3 October 2020	11	24
15. Q8 <i>also Topic 1</i>	A Level Paper 3 November 2021	13	27
16. Q12 <i>also Topic 4</i>	A Level Paper 3 June 2024	13	30
17. Q8 <i>also Topic 1</i>	A Level Paper 3 October 2020	14	34
9.2 INTERNAL ENERGY AND ABSOLUTE ZERO		3 Qs · 36 marks	36
18. Q4 <i>also Topic 11</i>	A Level Paper 3 October 2020	6	37
19. Q21 <i>also Topic 10</i>	A Level Paper 2 June 2025	13	38
20. Q12 <i>also Topic 5 & 8</i>	A Level Paper 3 June 2018	17	41
9.3 GAS LAWS AND THE IDEAL GAS EQUATION		4 Qs · 35 marks	44
21. Q2	A Level Paper 2 June 2018	1	45
22. Q18	A Level Paper 2 November 2021	9	46
23. Q4	A Level Paper 3 June 2024	9	48
24. Q11	A Level Paper 3 June 2019	16	50
9.4 KINETIC THEORY OF GASES		6 Qs · 40 marks	54
25. Q7	A Level Paper 2 June 2022	1	55
26. Q11	A Level Paper 2 June 2018	5	56
27. Q14	A Level Paper 2 June 2025	6	57
28. Q6	A Level Paper 3 June 2025	6	58
29. Q19	A Level Paper 2 June 2022	10	59



QUESTION		SOURCE	MARKS	PAGE
30.	Q17 <i>also Topic 4</i>	A Level Paper 2 June 2024	12	61



QUESTIONS

30 questions · 239 marks · 4 sub-topics



SUB-TOPIC 9.1

SPECIFIC HEAT CAPACITY AND SPECIFIC LATENT HEAT

Sub-topic 9.1 · 17 questions · 128 marks · lowest tariff first



5 A data book contains the following information for ethanol.

latent heat of fusion = 109 kJ kg^{-1}

latent heat of vaporisation = 838 kJ kg^{-1}

545 J is transferred from a sample of ethanol when it condenses.

Which of the following shows how to calculate the mass of ethanol that condenses?

- ☐ A $545 \div 109\,000$
- ☐ B $545 \div 838\,000$
- ☐ C $109\,000 \div 545$
- ☐ D $838\,000 \div 545$

(Total for Question 5 = 1 mark)



- 11** An electric iron rated at 2600 W contains a steel plate which is heated to a working temperature of 215 °C. Room temperature is 18 °C.

Deduce whether the plate could reach its working temperature in less than 1 minute.

mass of steel plate = 890 g

specific heat capacity of steel = 450 J kg⁻¹ K⁻¹

(3)

(Total for Question 11 = 3 marks)



- 11** A cup contains 180 g of black coffee at a temperature of 82 °C. 68 g of milk at a temperature of 2.7 °C is added to the coffee. An ideal temperature range for drinking coffee is said to be 50 °C to 60 °C.

Deduce whether the coffee will be within the ideal temperature range when the milk is added.

initial temperature of milk = 2.7 °C

specific heat capacity of black coffee = $4.2 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

specific heat capacity of milk = $3.9 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

(3)

(Total for Question 11 = 3 marks)



- 12** Latte is a type of coffee made with hot frothy milk. The milk is heated by pumping steam into it.

Calculate the maximum mass of milk that could be warmed to a temperature of 65°C by absorbing 15 g of steam at 100°C .

initial temperature of milk = 4.0°C

specific heat capacity of milk = $3900\text{ J kg}^{-1}\text{ K}^{-1}$

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

specific latent heat of vaporisation of water = $2.3 \times 10^6\text{ J kg}^{-1}$

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Maximum mass = ...

(Total for Question 12 = 4 marks)



- 11** A wet handkerchief is dried in 56 s using a hot iron rated at 2400 W.

Determine whether energy is transferred to the water in the handkerchief at a greater rate than it is transferred to the iron.

initial temperature of wet handkerchief = 18°C

initial mass of wet handkerchief = 35.9 g

final mass of dry handkerchief = 18.2 g

specific heat capacity of water = $4.19 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

specific latent heat of vaporisation of water = $2.26 \times 10^6 \text{ J kg}^{-1}$

(5)

(Total for Question 11 = 5 marks)



- 15** Aluminium is one of the most widely recycled metals. Aluminium cans are heated from room temperature until all the aluminium has melted. The molten aluminium is then used to make new cans. This process uses only 5% of the energy needed to extract aluminium from raw materials.

On a website it is claimed that recycling one aluminium can of mass 14 g saves enough energy to listen to music on a mobile phone continuously for 7 days.

Assess the validity of this claim.

melting point of aluminium = 660 K

specific heat capacity of aluminium = $902 \text{ J kg}^{-1} \text{ K}^{-1}$

specific latent heat of aluminium = 396 kJ kg^{-1}

room temperature = 293 K

mobile phone p.d. = 3.7 V

mobile phone current = 120 mA

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

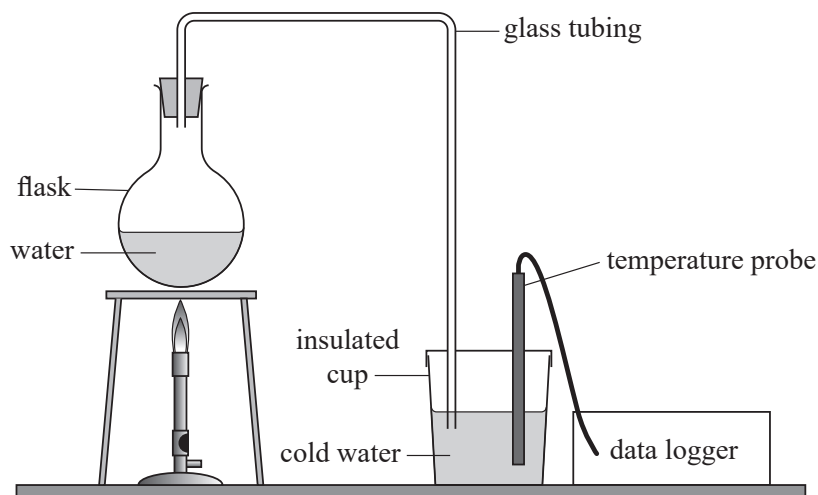
.....

.....

(Total for Question 15 = 6 marks)



- 7 A student carried out an experiment to determine the specific latent heat of vaporisation of water using the apparatus shown.



The water in the flask was heated and steam was forced out of the flask and through the glass tubing into the cold water in the insulated cup. The steam condensed as it passed into the cold water.

- (a) The initial temperature of the cold water was 18.5°C and the mass of water in the cup was 255.0 g . After steam had been passed through the water for some time the temperature had risen to 26.0°C and the mass of the water in the cup was 258.3 g .

Calculate the specific latent heat of vaporisation of water.

(3)

specific heat capacity of water = $4190\text{ J kg}^{-1}\text{ K}^{-1}$

.....

.....

.....

.....

.....

.....

.....

.....

Specific latent heat of vaporisation of water = ...

- (b) (i) Explain why the water was heated to boiling point and left boiling for a few minutes before the insulated cup of cold water was put in place.

(2)

- (ii) Identify a significant source of error in this experiment and the steps that should be taken to minimise its effect on the calculated value of the specific latent heat of vaporisation of water.

(2)

(Total for Question 7 = 7 marks)



2 A student determined the specific heat capacity of aluminium.

She used an electrical heater to heat an aluminium block and measured the temperature of the block with a digital thermometer.

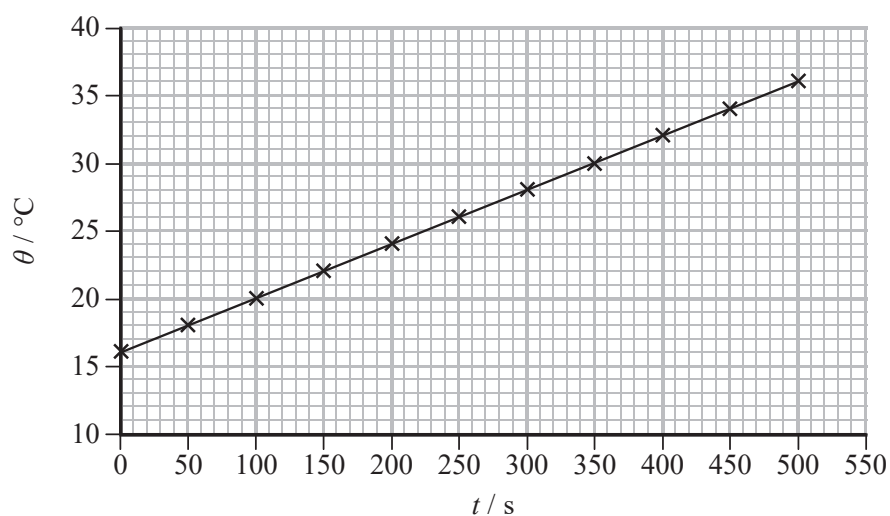
- (a) She connected the electrical heater into a circuit and took measurements to determine the power of the heater.

Draw a circuit diagram of a suitable circuit.

(2)

- (b) The student monitored the temperature θ of the aluminium block over the time t for which the heater was switched on.

Her results are plotted on the graph.



- (i) Determine the specific heat capacity of aluminium.

power of heater = 37.5 W

mass of aluminium block = 0.986 kg

(3)

Specific heat capacity of aluminium = ...

- (ii) The student looked up the accepted value for the specific heat capacity of aluminium. Using this value, the student predicted that it should have taken 240 s for the temperature of the aluminium block to increase by 10 °C.

Explain the difference between the predicted time and the student's actual observations.

(2)

(Total for Question 2 = 7 marks)



- 3 It was suggested on an online forum that it would be possible to cook a chicken by repeatedly slapping the chicken with one hand.

It was claimed that the energy transferred to a chicken in 8000 slaps would be sufficient to raise the temperature of the chicken from 23°C to 165°C .

In an investigation to test the claim, the effective mass of the hand was taken as 1.75 kg and the speed of the hand just before impact with the chicken as 6.25 m s^{-1} .

- (a) Deduce whether the data confirms that 8000 slaps would be sufficient.
Assume that no energy is transferred from the chicken to the surroundings.

mass of chicken = 0.875 kg

specific heat capacity of chicken = $1770\text{ J kg}^{-1}\text{ K}^{-1}$

efficiency of energy transfer from the hand = 65%

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

- (b) Explain whether the assumption made in (a) is realistic.

(2)

.....

.....

.....

.....

.....

(Total for Question 3 = 7 marks)



14 The fuel used in a camping stove is butane, which is stored in a canister as shown.



Some of the butane in the canister is in a liquid state, and some is a gas.

(a) When the stove uses the butane gas, some of the liquid butane evaporates.

Explain why the temperature of the canister decreases when the stove is used.

(3)

.....

.....

.....

.....

.....

.....

(b) The pressure inside the canister is 220 kPa and the temperature of the gas is 21 °C.

(i) The canister is in the shape of a cylinder of length 0.23 m and radius 0.11 m.

Calculate the number of molecules of butane gas in the canister.

Assume the volume of liquid butane inside the canister is negligible.

(4)

.....

.....

.....

.....

.....

.....

.....

Number of molecules of butane gas = ...

(ii) Calculate the r.m.s. speed of the molecules of butane gas.

mass of butane molecule = 9.6×10^{-26} kg

(2)

.....

.....

.....

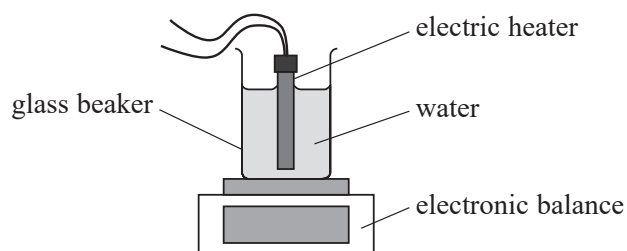
.....

r.m.s. speed = ...

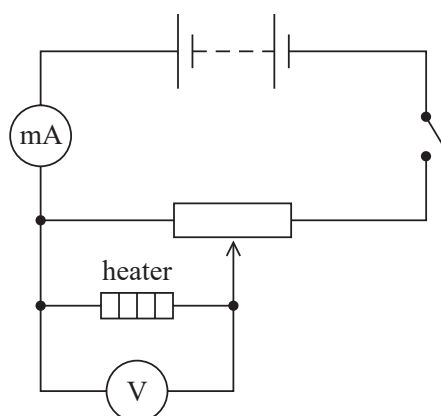
(Total for Question 14 = 9 marks)



- 3 The specific latent heat of vaporisation of water can be determined using the apparatus shown.



- (a) A student planned to vary the current in the heater from 0 A to 5 A. The student connected the following circuit to measure the current in the heater.



Criticise the student's circuit.

(2)

.....

.....

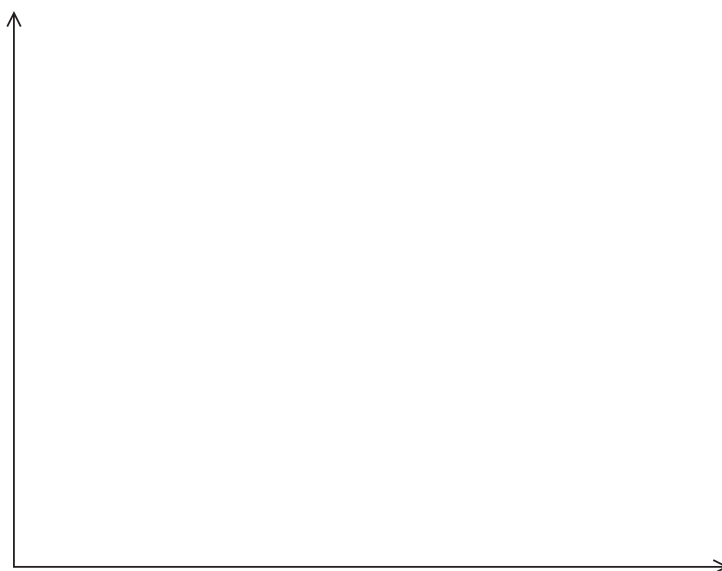
.....

.....

- (b) (i) The student corrected the circuit and closed the switch. He waited until the water started boiling. He started a stopwatch and recorded the readings on the balance at regular time intervals.

Sketch a graph, on the axes below, of how the readings on the balance would vary with time.

(3)



- (ii) The heater was switched on for 6.0 minutes and the change in mass of water in the beaker was 7.5 g.

Calculate the specific latent heat of vaporisation of water, L .

$$V = 12 \text{ V}$$

$$I = 4.2 \text{ A}$$

(3)

.....

.....

.....

.....

.....

$$L = \text{.....}$$



- (iii) The errors in the experiment include uncertainty in the mass reading and uncertainty in reading the stopwatch, as the water boils.

Explain how another significant source of error affects the value of L obtained from the experiment.

(2)

(Total for Question 3 = 10 marks)

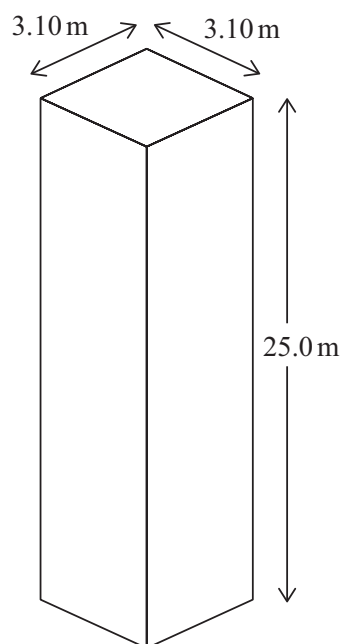


- 19 The photograph shows a giant ice sculpture of the Elizabeth Tower (Big Ben). The ice sculpture was installed in St Pancras station in London in 2009.



(Source: © Skye Hohmann / Alamy Stock Photo)

The ice sculpture can be approximated as a regular cuboid, as shown below.



- (a) Show that the mass of the ice sculpture is about 2.2×10^5 kg.

density of ice = 920 kg m^{-3}

(2)

.....

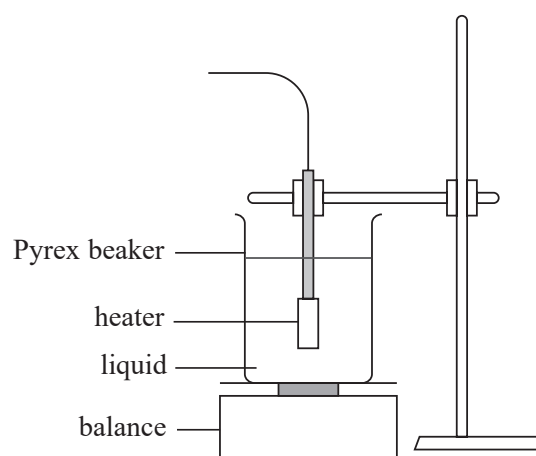
.....

.....

.....

- 6 A student determined the latent heat of vaporisation of a liquid using an electrical heater to boil the liquid in a Pyrex beaker.

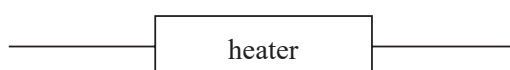
The apparatus used is shown below.



- (a) She connected the heater into a circuit and took measurements of the potential difference V and the current I for the heater.

Complete the circuit diagram to show a suitable circuit.

(2)



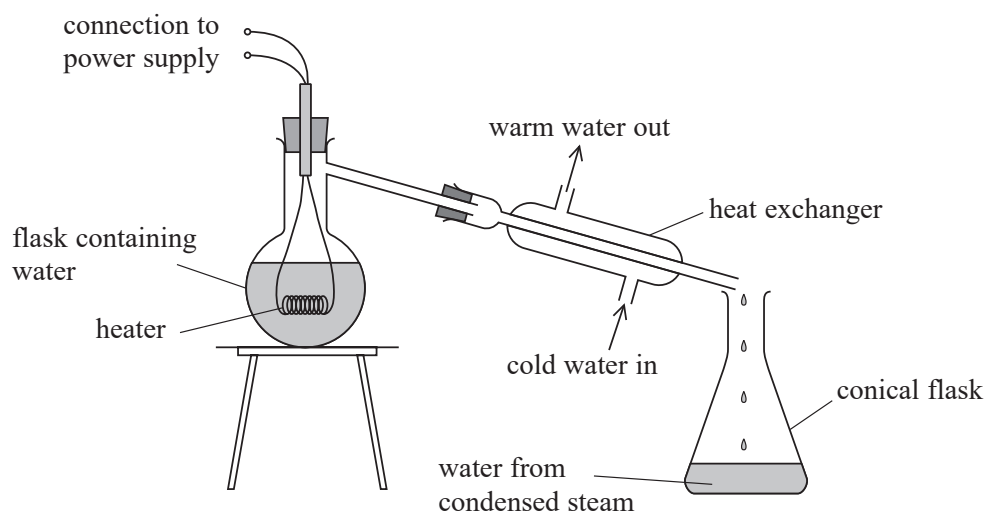
(c) Explain how this method might be modified to improve the accuracy of the student's conclusion.

(2)

(Total for Question 6 = 11 marks)



- 8 The apparatus shown can be used to determine a value for the specific latent heat of vaporisation of water.



- (a) In one experiment the current in the heater was 8.20 A, and the potential difference across the heater was 230 V.

(i) Show that the power of the heater was about 2 kW.

(2)

.....

.....

.....

- (ii) There was 0.655 kg of water in the flask at an initial temperature of 22.5 °C. The heater was switched on, and the water in the flask was heated to boiling point.

Calculate the minimum time taken for the water to be heated to 100.0 °C.

specific heat capacity of water = 4190 J kg⁻¹ K⁻¹

(3)

.....

.....

.....

.....

.....

Minimum time taken for water to be heated = ...

(b) The heater was left on and water continued to boil in the flask. The water was allowed to boil for a few minutes. The conical flask was then placed under the heat exchanger and water was collected in it.

- (i) Give a reason why the water was left boiling for a few minutes before the conical flask was put in place.

(1)

.....

.....

.....

.....

- (ii) Water with a mass of 95.0 g was collected in a time of 125 s.

Calculate the rate of energy transfer in the heat exchanger.

specific latent heat of vaporisation of water = $2.26 \times 10^6 \text{ J kg}^{-1}$

(3)

.....

.....

.....

.....

.....

Rate of energy transfer in the heat exchanger = ...

- (iii) Discuss your answers to (a)(i) and (b)(ii).

(3)

.....

.....

.....

.....

.....

.....



(c) State how the apparatus could be modified to minimise the effect of a significant source of error.

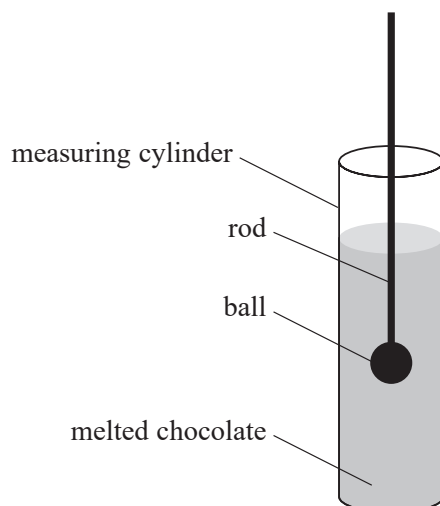
(1)

(Total for Question 8 = 13 marks)



12 Chocolate is a solid at room temperature, but melts just below body temperature.

- (a) A student investigated the viscosity of some melted chocolate using a falling-ball method. Since chocolate is opaque, a thin rod was attached to the ball so that the movement of the ball could be monitored. The apparatus is shown in the diagram.



The chocolate was maintained at a constant temperature during the investigation.

- (i) The student used a stopwatch to measure the time t for the ball to fall 22.5 cm whilst travelling at its terminal velocity v .

Her results are shown in the table.

t_1 / s	t_2 / s	t_3 / s
9.6	9.9	9.6

v is given by the formula

$$v = \frac{2r^2 g(\rho_B - \rho_C)}{9\eta}$$

where

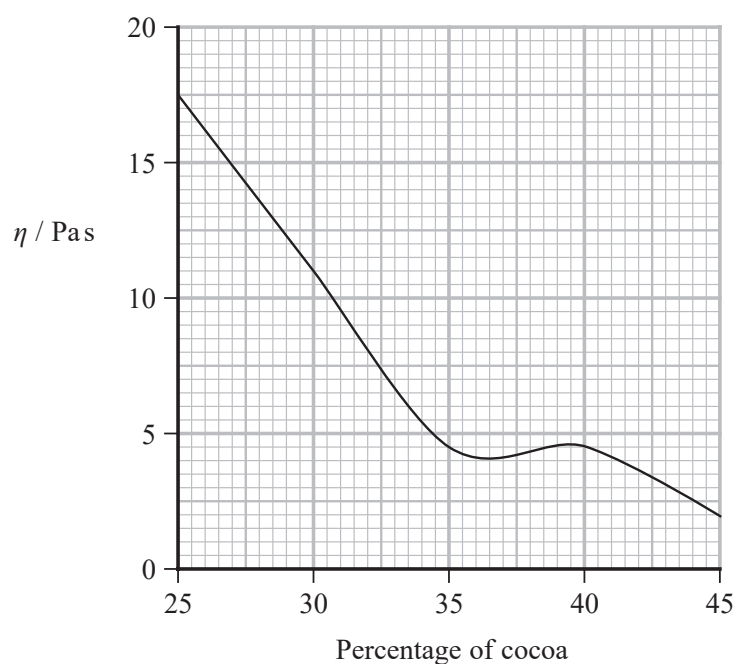
r is the radius of the ball

ρ_B is the density of the ball

ρ_C is the density of the chocolate

η is the viscosity of the chocolate.

The graph is taken from a commercial website. It shows how, at the temperature of the experiment, η depends on the percentage of cocoa in the chocolate.



The chocolate wrapper indicated that the chocolate had a 35% cocoa content.

Assess whether the student's timing data supports this percentage cocoa content.

$$r = 4.25 \times 10^{-3} \text{ m}$$

$$\rho_B = 7750 \text{ kg m}^{-3}$$

$$\rho_C = 1330 \text{ kg m}^{-3}$$

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



- (ii) Explain one reason why the student's data may have led to an inaccurate conclusion about the cocoa content.

(2)



(b) One type of chocolate melts at a temperature of 32°C .

The energy released when 65 g of this chocolate is digested is 345 kcal.

It is suggested that the energy used to melt a piece of this chocolate is at least 15% of the energy released when the chocolate is digested.

Assess the accuracy of this suggestion.

initial temperature of chocolate = 15°C

specific heat capacity of chocolate = $3.9 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

specific latent heat of chocolate = $1.50 \times 10^5 \text{ J kg}^{-1}$

1 kcal = 4200 J

(6)

(Total for Question 12 = 13 marks)



- 8 A student investigated the rate at which a hot liquid transfers thermal energy to the surroundings. He placed hot water in a Pyrex beaker and measured the temperature of the water using a liquid-in-glass thermometer.

He obtained the following data for the temperature θ of the water at times t . He measured t using a stopwatch.

t / s	$\theta / ^\circ\text{C}$		
0	95		
120	87		
240	81		
360	76		
480	71		

temperature of surroundings = 23°C

Theory suggests that a liquid transfers internal energy to the surroundings at a rate proportional to the temperature difference $\Delta\theta$ between the liquid and the surroundings.

This leads to the expression

$$\Delta\theta = \Delta\theta_0 e^{-bt}$$

where b is a constant and $\Delta\theta_0$ is the initial temperature difference.

- (a) Explain why a graph of $\ln \Delta\theta$ against t should be a straight line.

(2)

.....

.....

.....

.....

- (b) (i) Plot a graph of $\ln \Delta\theta$ against t on the grid opposite.
Use the columns provided in the table to show any processed data.

(5)



(ii) Determine the value of b .

(3)

$$b = \dots\dots\dots$$

(c) The student suggested that the experiment would have been more accurate if a temperature sensor and data logger had been used to collect the data.

Assess the validity of the student's suggestion.

(4)

(Total for Question 8 = 14 marks)



SUB-TOPIC 9.2

INTERNAL ENERGY AND ABSOLUTE ZERO

Sub-topic 9.2 · 3 questions · 36 marks · lowest tariff first



- *4 Radium is a radioactive element. The most common isotope of radium has a half-life of almost two thousand years. A sample of radium can remain at a higher temperature than its surroundings for a long period of time.

Explain how a sample of radium is able to release significant amounts of energy over a long period of time.

(6)

(Total for Question 4 = 6 marks)

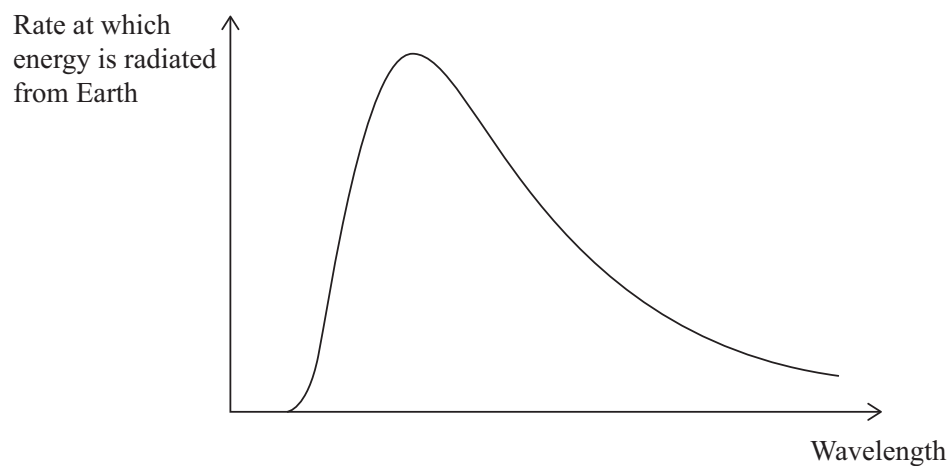


21 All objects with a temperature above absolute zero emit a spectrum of electromagnetic radiation.

(a) State what is meant by absolute zero.

(1)

(b) The graph shows how the intensity of radiation emitted by the Earth varied with wavelength in 2020.



Explain the differences between this graph and a graph representing the emission of radiation by the Earth in 2050. Assume that the average global temperature increases over time.

(4)

(c) At the end of the 19th century, Wien investigated the radiation emitted by hot objects and formulated a law.

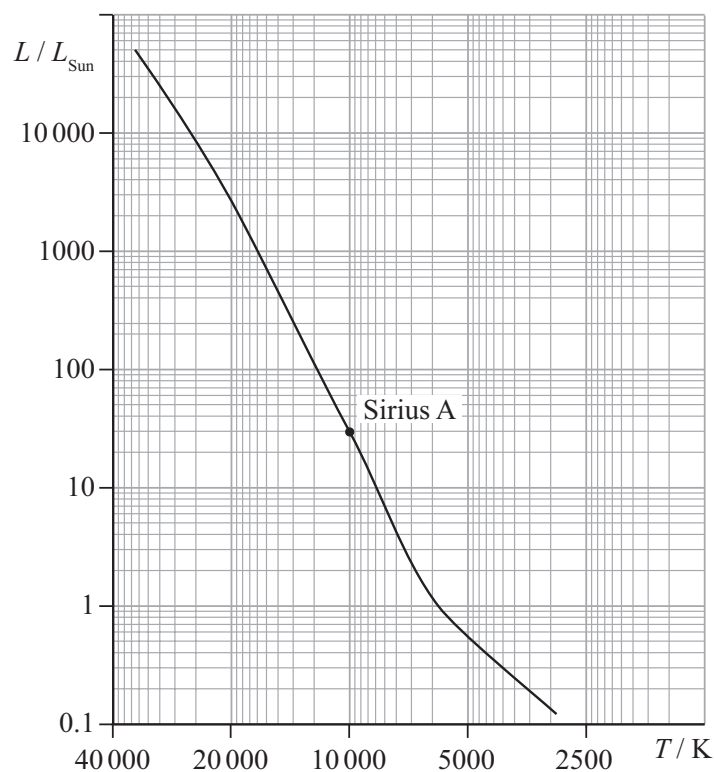
The table shows data for some stars.

Star	$\lambda_{\text{max}} / \text{nm}$	T / K
Bellatrix	132	21 500
Rigel	245	11 600
Sirius	287	9910

Deduce whether Wien’s law is confirmed by this data.

(3)

- (d) The Hertzsprung–Russell diagram below shows part of the main sequence of stars. The star Sirius A is marked on the diagram.



On a website it states that the radius of Sirius A is twice the radius of the Sun.

Deduce whether this statement is correct.

radius of the Sun = $6.96 \times 10^8 \text{ m}$

surface temperature of the Sun = 5800 K

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question 21 = 13 marks)



12 Our understanding of the atom has developed over time, from early models in which atoms were considered to be hard incompressible spheres, through to the nuclear model of the atom and the ladder model in which electrons exist in a discrete number of allowed energy states.

*(a) The model of atoms as hard incompressible spheres, moving rapidly and randomly, can be used to explain why gases exert a pressure.

Explain, using ideas of momentum, why the pressure exerted by a gas increases as the temperature of the gas increases.

(6)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....



(b) The nuclear model of the atom was established following a series of experiments in which alpha particles were directed at thin gold foil.

- (i) An alpha particle approaching a gold nucleus, ${}_{79}^{197}\text{Au}$, head-on will be brought to rest and returned along its original path.

Calculate the minimum distance between the alpha particle and the nucleus for alpha particles of energy of 5.5 MeV.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

Minimum distance = ...

- (ii) It is observed that electrons, with energy of 5.5 keV, are diffracted as they pass through the thin gold foil.

Explain a conclusion about the electrons that can be made from this observation.

(3)

.....

.....

.....

.....

.....

.....

- (c) In the energy ladder model of the atom, electrons exist in a discrete number of allowed energy states. The collision of electrons with gold atoms may lead to the production of high frequency electromagnetic radiation.

Explain how high frequency electromagnetic radiation may be produced when electrons collide with atoms in a metal.

(4)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

(Total for Question 12 = 17 marks)



SUB-TOPIC 9.3

GAS LAWS AND THE IDEAL GAS EQUATION

Sub-topic 9.3 · 4 questions · 35 marks · lowest tariff first



2 A sample of an ideal gas has pressure p , volume V and absolute temperature T .

The volume of the gas is decreased to $\frac{2}{3}V$ and the temperature increased to $\frac{6}{5}T$.

Which of the following is the new pressure of the gas?

☐ A $\frac{5}{9}p$

☐ B $\frac{4}{5}p$

☐ C $\frac{5}{4}p$

☐ D $\frac{9}{5}p$

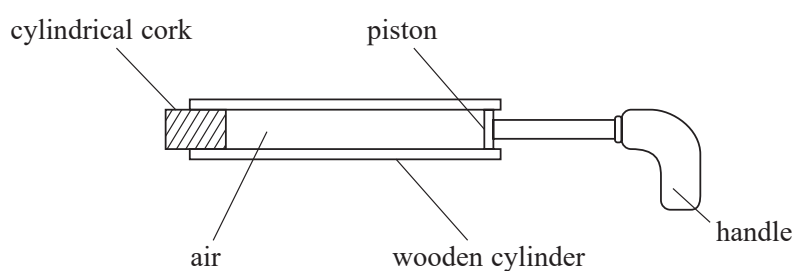
(Total for Question 2 = 1 mark)



18 The photographs show a wooden pop gun before and after the cork is popped.



The diagram shows a cross-section through the pop gun.



Initially the piston is at the right-hand end of the cylinder, as shown. Then the cork is pushed into the other end of the cylinder.

When the handle is pushed in, the pressure of the air in the cylinder increases. This exerts an additional force on the cork.

Once the additional force is sufficient to overcome the frictional force between the cork and the cylinder, the cork is pushed out.

(a) Show that the pressure of the air in the cylinder must be about $2 \times 10^5 \text{ Pa}$ in order to push the cork out.

maximum frictional force = 8.8 N

cross-sectional area of cork = $9.2 \times 10^{-5} \text{ m}^2$

atmospheric pressure = $1.0 \times 10^5 \text{ Pa}$

(3)

.....

.....

.....

.....

.....

- (b) Calculate the temperature of the gas in the cylinder at the instant the cork is expelled.

volume of air in the cylinder with the handle pulled out = $1.1 \times 10^{-5} \text{ m}^3$

volume of air in the cylinder at the moment the cork is pushed out = $6.7 \times 10^{-6} \text{ m}^3$

atmospheric pressure = $1.0 \times 10^5 \text{ Pa}$

initial temperature of air = 19°C

(2)

Temperature = ...

- (c) The formulae sheet for this paper includes the equation

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

Derive the equation $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$

(2)

- (d) Calculate the root mean square speed of the molecules of air in the cylinder before the handle is pushed in.

average mass of molecule of air = $4.8 \times 10^{-26} \text{ kg}$

temperature of air = 19°C

(2)

Root mean square speed = ...

(Total for Question 18 = 9 marks)



4 Helium is available in small metal canisters. The helium can be used to fill party balloons.

- (a) A full canister contains helium gas at a temperature of 18.5°C and a pressure of $1.65 \times 10^7 \text{ Pa}$. The canister is approximately spherical, with a radius of $4.36 \times 10^{-2} \text{ m}$.

Calculate the mass of helium gas in the full canister.

$$\text{mass of } 6.02 \times 10^{23} \text{ atoms of helium} = 4.00 \times 10^{-3} \text{ kg}$$

(5)

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Mass of helium = ...



- (b) Student X and Student Y discuss the weight of the canister and its contents after a number of balloons have been filled.

Student X suggests that the weight will have increased, because the upthrust exerted on the canister by the helium will be reduced.

Student Y suggests that the weight will have decreased, because helium has been released from the canister.

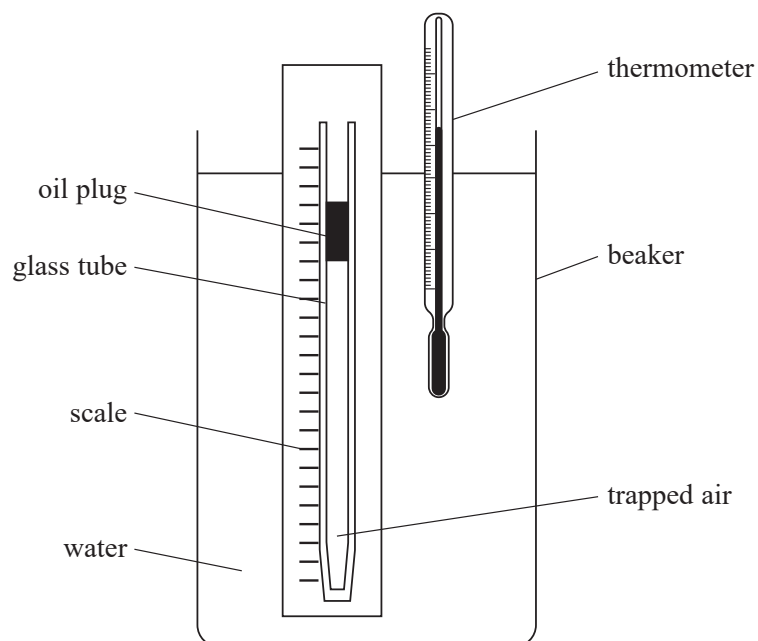
Assess which student's suggestion is correct.

(4)

(Total for Question 4 = 9 marks)



- 11 A student investigated how the volume of a fixed mass of air varies with the temperature of the air. She used the apparatus shown.



A glass tube was sealed at one end. A plug of oil trapped a length l of air in the tube. The water in the beaker was heated to a temperature θ . The corresponding value of l was measured. This was repeated for a range of temperatures.

The thermometer had a resolution of 0.5°C . The scale had mm divisions.

The student's results are shown in the table.

$\theta / ^\circ\text{C}$	l / cm
24	8.8
60	9.8
78.5	10.3
95.5	10.9

- (a) (i) Criticise the student's results.

(3)

.....

.....

.....

.....

.....

(ii) Explain two possible sources of error in this investigation.

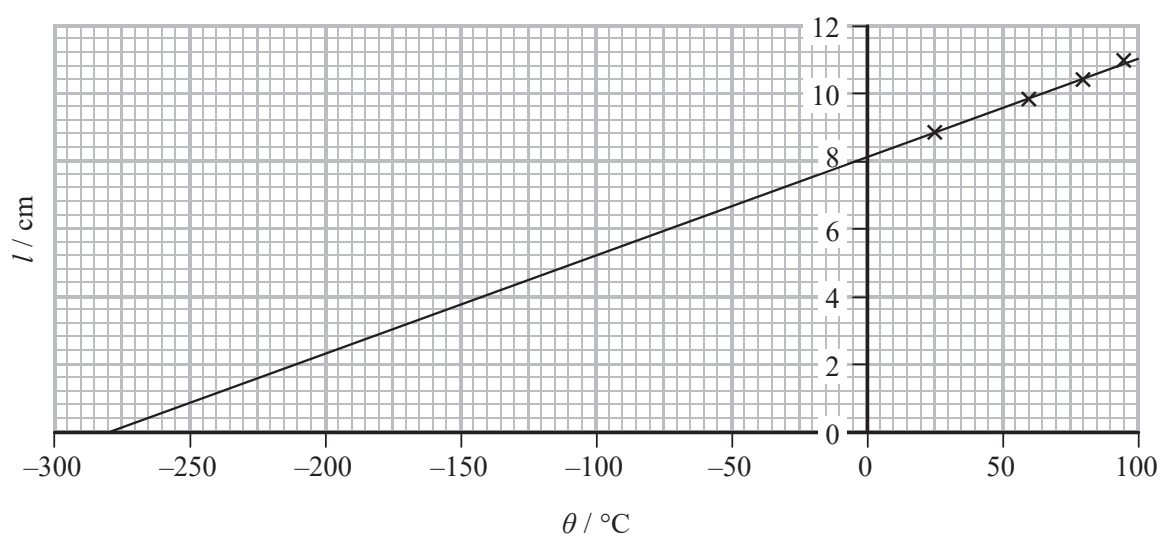
(4)

(iii) Describe two improvements that would increase the accuracy of measurements obtained in this investigation.

(2)



(b) The student plotted a graph of l against θ as shown.



(i) Explain the significance of the intercept on the x -axis.

(3)

.....

.....

.....

.....

.....

.....

- (ii) The student wrote a report of the investigation in her lab book. In the conclusion she wrote:

"In this investigation uncertainties were minimised by selecting measuring instruments with a high resolution. The points lie on a perfect straight line, indicating that the investigation is accurate."

Discuss the student's conclusion.

(4)

(Total for Question 11 = 16 marks)



SUB-TOPIC 9.4

KINETIC THEORY OF GASES

Sub-topic 9.4 · 6 questions · 40 marks · lowest tariff first



- 7 Air is trapped in a glass tube. When the air is forced into a smaller volume at a constant temperature, the pressure increases.

Which of the following statements about air molecules is a reason why the pressure the trapped air exerts on the tube increases?

- ☐ A The molecules have a greater mean kinetic energy.
- ☐ B The molecules make more frequent collisions with each other.
- ☐ C The molecules make more frequent collisions with the walls of the tube.
- ☐ D The molecules experience a greater change in momentum when they collide with the tube.

(Total for Question 7 = 1 mark)

- 11 (a) For an ideal gas $pV = NkT$ and $pV = \frac{1}{3}Nm \langle c^2 \rangle$.

Use these relationships to show that the mean kinetic energy of a gas molecule is proportional to the absolute temperature.

(2)

.....

.....

.....

.....

.....

.....

- (b) The molecules in a sample of gas have a mass of 5.0×10^{-26} kg.

Calculate the root-mean-square speed of gas molecules in the gas at 25°C .

(3)

.....

.....

.....

.....

.....

.....

Root-mean-square speed = ...

(Total for Question 11 = 5 marks)



*6 Air at room temperature was sealed in a closed container. The container was placed in an ice bath and the temperature of the air decreased. The volume of the container remained constant.

Explain what happened to the pressure exerted by the air. In your response you should refer to the momentum of the air molecules.

(Total for Question 6 = 6 marks)



19 A fine-beam tube is used for investigating properties of electrons.

An electron beam is produced inside a spherical glass bulb. The bulb contains neon gas at a very low pressure.

(a) The neon gas is at a pressure of 1.25 Pa and a temperature of 25 °C.

Calculate the number N of neon atoms inside the bulb.

bulb diameter = 16.0 cm

(4)

.....

.....

.....

.....

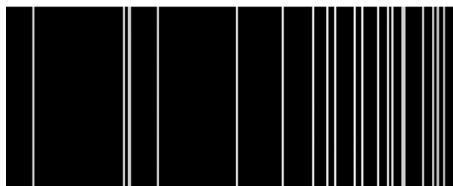
.....

.....

$N =$



*(b) Interactions between electrons and the neon atoms in the tube make the beam visible. Part of the spectrum of visible light produced by these interactions is shown.



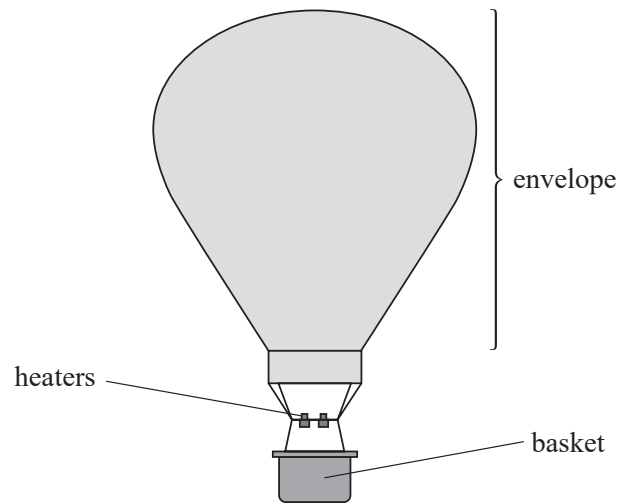
(Source: © MoFarouk/Shutterstock)

Explain the process that results in the emission of this spectrum. Your answer should include reference to energy levels in atoms.

(6)

(Total for Question 19 = 10 marks)

17 (a) A hot air balloon consists of a fabric envelope, heaters and a basket, as shown.



When the balloon is set up, the envelope is partly filled with air at 20°C . The air is then heated to 120°C and expands to fill the envelope and becomes less dense.

The air pressure inside the envelope is always equal to the air pressure outside the envelope because the envelope is open at the bottom.

The balloon takes off when the upthrust is more than the total weight of the balloon, the air in the envelope and the passengers.

Deduce whether the balloon can take off.

volume of air at 120°C in inflated envelope = 2800 m^3

density of air at 20°C = 1.2 kg m^{-3}

mass of balloon = 380 kg

mass of passengers = 340 kg

upthrust when the envelope is full = $33\,000\text{ N}$

(6)



- (iii) Calculate the root-mean-square speed of nitrogen molecules at a temperature of 120°C .

mass of nitrogen molecule = 28 u

(3)

.....

.....

.....

.....

.....

Root-mean-square speed = ...

(Total for Question 17 = 12 marks)



MARK SCHEMES

official mark schemes



5	B – $545 \div 838\,000$	1
	Incorrect Answers: Correct method: $\text{mass} = \text{energy transfer} \div \text{latent heat of vaporisation}$ A – uses $\text{energy transfer} \div \text{latent heat of fusion}$ C – uses $\text{latent heat of fusion} \div \text{energy transfer}$ D – uses $\text{latent heat of vaporisation} \div \text{energy transfer}$	



Question Number	Acceptable answers	Additional guidance	Mark
11	• use of $\Delta E = mc\Delta\theta$ • use of $P = E/t$ • Correct calculation of an appropriate quantity and comment consistent with their value.	(1) MP2 Candidates need to calculate either a time, a final temperature, an energy or a power (1) Examples: Yes, because $t = 30$ s, which is less than one minute Or Yes, because it could reach temperature of 408°C in one minute Or Yes, because it would transfer $156\,000$ J in one minute Or Yes, because the power required is 1.3 kW <u>Example of calculation</u> $\Delta E = 0.89 \text{ kg} \times 450 \text{ J kg}^{-1} \text{ K}^{-1} \times (215^\circ\text{C} - 18^\circ\text{C})$ $= 78\,900 \text{ J}$ $t = 78\,900 \text{ J} \div 2600 \text{ W} = 30 \text{ s}$	3

(Total for Question 11 = 3 marks)



Question Number	Acceptable answers	Additional guidance	Mark
11 a	- Use of $\Delta Q = mc\Delta\theta$ (1) ... for correct temperature differences (1) - Final temperature is 61.4 °C which is above range (1)	<u>Example of calculation</u> $0.180 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{ K}^{-1} \times (82 \text{ °C} - \theta_f)$ $= 0.068 \text{ kg} \times 3900 \text{ J kg}^{-1} \text{ K}^{-1} \times (\theta_f - 2.7 \text{ °C})$ $\theta_f = 61.4 \text{ °C}$ Answers making comparisons based on equivalent Physics may be awarded MP3 e.g. 16 600 J must be transferred from coffee to reach 60°C but required energy transfer to milk is only 15 200 J	3

(Total for Question 11 = 3 marks)

Question Number	Acceptable answers	Additional guidance	Mark
-----------------	--------------------	---------------------	------

Question Number	Acceptable answers	Additional guidance	Mark
12	- Use of increase in thermal energy of milk = latent heat energy released by steam + decrease in thermal energy of condensed steam (1) - Use of $\Delta Q = mc\Delta\theta$ (1) - Use of $\Delta Q = L\Delta m$ (1) $m = 0.15 \text{ kg}$ (150 g) (1)	<u>Example of calculation</u> $(mc\Delta\theta)_{\text{milk}} = (mc\Delta\theta)_{\text{water}} + L\Delta m_{\text{steam}}$ $m \times 3900 \text{ J kg}^{-1} \text{ K}^{-1} \times (65.0 \text{ }^{\circ}\text{C} - 4.00 \text{ }^{\circ}\text{C})$ $= (0.015 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{ K}^{-1} \times (100 \text{ }^{\circ}\text{C} - 65.0 \text{ }^{\circ}\text{C}))$ $+ (2.3 \times 10^6 \text{ J kg}^{-1} \times 0.015 \text{ kg})$ $m = 0.15 \text{ kg}$	4

(Total for Question 12 = 4 marks)



Question Number	Acceptable answers	Additional guidance	Mark
11	• Use of $\Delta Q = mc\Delta\theta$ (1) • for correct temperature change (1) • Use of $\Delta Q = L\Delta m$ (1) • Use of $P = E/t$ (1) • It is not transferred faster because: (1) 823 (W to water) < 2400 (W to iron) Or 46 100 (J to water) < 134 400 (J to iron) Or 19.2 (s to evaporate water at rate of 2400 W) < 56 (s taken)	<u>Example of calculation</u> mass of water = 0.0359 kg – 0.0182 kg = 0.0177 kg $\Delta Q = 0.0177 \text{ kg} \times 4190 \text{ J kg}^{-1} \text{ K}^{-1} \times (100 \text{ }^{\circ}\text{C} - 18 \text{ }^{\circ}\text{C})$ = 6100 J $\Delta Q = (0.0177 \text{ kg}) \times 2.26 \times 10^6 \text{ J kg}^{-1}$ = 40 000 J $P = (6100 \text{ J} + 40 000 \text{ J}) / 56 \text{ s} = 823 \text{ W}$	5

(Total for Question 11 = 5 marks)



Question Number	Acceptable answers	Additional guidance	Mark
12	- Energy lost by block = energy gained by water and/ or glass (1) - Use of $\Delta E = mc\Delta\theta$ (1) - using temperature change of block (1) $c = 310 \text{ (J kg}^{-1} \text{ K}^{-1}\text{)}$ Or Required temperature change for tin = 103 K Or required starting temperature for tin = 126 °C (1) - Block is copper with justification e.g. some energy transferred to surroundings (so causes an underestimate in c) or block not fully at 100°C (so causes an underestimate in c) or tin cannot produce the required temperature change (1)	<u>Example of calculation:</u> $0.22 \text{ kg} \times c \times (100 - 23)\text{K}$ $= 0.05 \text{ kg} \times 840 \text{ J kg}^{-1} \text{ K}^{-1} \times 4 \text{ K} + 0.3 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{ K}^{-1} \times 4 \text{ K}$ $16.94 c = 168 + 5040 = 5208 \text{ J}$ $c = 307 \text{ J kg}^{-1} \text{ K}^{-1}$ MP1 may be awarded for approach comparing energy gained by water and/or glass with maximum energy lost by block without equating them	5

(Total for Question 12 = 5 marks)



Question Number	Acceptable answers	Additional guidance	Mark
15	• Use of $\Delta E = mc\Delta\theta$ (1) • Use of $\Delta E = L\Delta m$ (1) • Apply 5% to calculate energy saved (1) • Use of $P = VI$ or Use of $Q = It$ (1) • Use of $P = \frac{W}{t}$ or Use of $E = QV$ (1) • 2.69×10^5 J compared with 1.93×10^5 J for energy saved, and concludes claim invalid. (1) Or a phone could run for 5 days compared to 7 days and conclusion claim invalid Or a phone could run for 433 900 s compared to 604 800 s and conclusion claim invalid	<u>Example of calculation:</u> For aluminium when being heated up to m.pt.: $\Delta E = 14 \times 10^{-3} \text{ kg} \times 902 \text{ J kg}^{-1} \text{K}^{-1} \times (660 - 293) \text{K}$ $\Delta E = 4.63 \times 10^3 \text{ J}$ For aluminium when melting: $\Delta E = 14 \times 10^{-3} \text{ kg} \times 396 \times 10^3 \text{ J kg}^{-1} = 5.54 \times 10^3 \text{ J}$ Energy saved = $\frac{0.95}{0.05} \times (4630 + 5540) \text{J}$ Energy saved = $1.93 \times 10^5 \text{ J}$ $P = 3.7 \text{ V} \times 120 \times 10^{-3} \text{ A} = 0.444 \text{ W}$ $\Delta E = 0.444 \text{ W} \times 7 \times 24 \times (60 \times 60) \text{s} = 2.69 \times 10^5 \text{ J}$	6

(Total for Question 15 = 6 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
7 (a)	- Use of $\Delta E = L\Delta m$ (1) - Use of $\Delta E = mc\Delta\theta$ (1) $L = 2.1 \times 10^6 \text{ J kg}^{-1}$ (1)	In MP1 Δm must be an attempt at a mass difference In MP2 allow any m, $\Delta\theta$ from the question data <u>Example of calculation</u> heat transfer as steam condenses = $(258.3-255.0) \times 10^{-3} \text{ kg} \times L$ heat transfer as steam cools = $3.3 \times 10^{-3} \text{ kg} \times 4190 \text{ J kg}^{-1} \text{ K}^{-1} \times (100-26) \text{ K}$ heat transfer as water is heated = $0.255 \text{ kg} \times 4190 \text{ J kg}^{-1} \text{ K}^{-1} \times (26-18.5) \text{ K}$ $\therefore 3.3 \times 10^{-3} \text{ kg} \times L + 1023 \text{ J} = 8013 \text{ J}$ $\therefore L$ $= \frac{8013 \text{ J} - 1023 \text{ J}}{3.3 \times 10^{-3} \text{ kg}} = 2.12 \times 10^6 \text{ J kg}^{-1}$	3
7(b)(i)	An explanation that makes reference to the following: (1) - To bring tubing up to temperature (of steam) - So steam only condenses in the cup (1) Or steam doesn't condense in the tubing		2
7(b)(ii)	- Thermal energy will be transferred from the steam/tubing to the surroundings (1) - Lagging/insulating/shortening the tubing (1)	Accept: - Thermal energy is transferred to the cup/ probe - These should have a small a heat capacity	2

(Total for Question 7 = 7 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	- Series circuit including power supply, heater and ammeter. (1) - Voltmeter connected in parallel with heater (1)		2
2(b)(i)	- Change in temperature and corresponding time (1) - Use of $P = \Delta E / \Delta t$ and $\Delta E = mc\Delta\theta$ (1) $c = 950 \text{ J kg}^{-1} \text{ K}^{-1}$ (1)	Example of calculation: $\frac{\Delta\theta}{\Delta t} = \frac{(36 - 16) \text{ K}}{(500 - 0) \text{ s}} = 0.04 \text{ K s}^{-1}$ $37.5 \text{ W} = 0.986 \text{ kg} \times c \times 0.04 \text{ K s}^{-1}$ $c = 951 \text{ J kg}^{-1} \text{ K}^{-1}$	3
2(b)(ii)	An explanation that makes reference to the following points: - In 240 s the temperature of the block rose by only 9.6 °C Or It took 250 s for the temperature of the block to rise by 10 °C. (1) - Hence there must have been energy transfer to the surroundings (by heating) (1)	For MP1 accept 9.5 °C Accept it took 10 s longer For MP2 accept energy dissipated to the surroundings	2

(Total for Question 2 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)	• Use of $E_K = \frac{1}{2}mv^2$ (1) • Use of $\Delta E = mc\Delta\theta$ (1) • Use of 8000 Or use of (energy required) / (energy per slap) (1) • Use of 65% with input energy (1) • Energy from 8000 slaps would be 1.78×10^5 J which is less than the energy required to raise the temperature to 165°C (2.20×10^5 J) Or final temperature would be 138°C, so not enough Or 9900 slaps would be needed, so not enough Or temperature rise from 8000 slaps is 115 K which is less than required temperature rise of 142 K (1)	<u>Example of calculation</u> $E_K = \frac{1}{2} \times 1.75 \text{ kg} \times (6.25 \text{ m s}^{-1})^2 = 34.2 \text{ J}$ $\Delta E = 0.65 \times 8000 \times 34.2 \text{ J} = 1.78 \times 10^5 \text{ J}$ $\Delta E = 0.875 \text{ kg} \times 1770 \text{ J kg}^{-1}\text{K}^{-1} \times (165 - 23)\text{K}$ $\therefore \Delta E = 2.20 \times 10^5 \text{ J}$ $E_K = \frac{1}{2} \times 1.75 \text{ kg} \times (6.25 \text{ m s}^{-1})^2 = 34.2 \text{ J}$ $\Delta E = 0.65 \times 34.2 \text{ J} = 22.2 \text{ J}$ $\Delta E = 0.875 \text{ kg} \times 1770 \text{ J kg}^{-1}\text{K}^{-1} \times (165 - 23)\text{K}$ $\therefore \Delta E = 2.20 \times 10^5 \text{ J}$ $\text{Number of slaps} = \frac{2.20 \times 10^5 \text{ J}}{22.2 \text{ J}} = 9910$ $E_K = \frac{1}{2} \times 1.75 \text{ kg} \times (6.25 \text{ m s}^{-1})^2 = 34.2 \text{ J}$ $\Delta E = 0.65 \times 8000 \times 34.2 \text{ J} = 1.78 \times 10^5 \text{ J}$ $1.78 \times 10^5 \text{ J} = 0.875 \text{ kg} \times 1770 \text{ J kg}^{-1}\text{K}^{-1} \times (T_f - 296)\text{K}$ $\therefore T_f = \frac{1.78 \times 10^5 \text{ J}}{1.55 \times 10^3 \text{ J K}^{-1}} + 296 \text{ K} = 411 \text{ K}$ $\therefore \theta_f = (411 - 273) \text{ K} = 138^\circ\text{C}$ MP5: must see a correct value as part of the conclusion	5



3(b)	- There is no way to insulate the chicken from the surroundings Or there will be energy transfer if there is a temperature difference with the surroundings Or there will be energy transfer unless the chicken is in thermal equilibrium with the surroundings Or energy will be transferred to the surroundings between slaps Or it would take a long time for 8000 slaps so there will be energy transfer (1) - So the assumption is unrealistic (dependent mark) (1)	MP1: accept lag	2
------	---	-----------------	---

(Total for Question 3 = 7 marks)



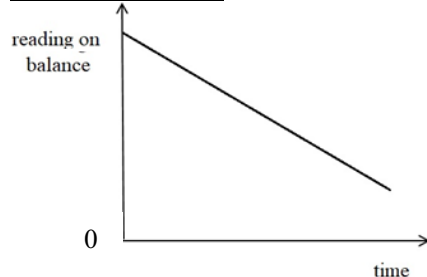
Question Number	Acceptable answers	Additional guidance	Mark
14(a)	An explanation that makes reference to the following points: - There is an increase in the potential energy of molecules leaving the liquid Or latent heat must be supplied to convert liquid to gas Or only faster molecules have enough energy to escape Or work is done by the expanding gas (1) - The internal energy of the liquid decreases Or the average kinetic energy of the molecules remaining in the liquid decreases (1) - so the temperature of the liquid decreases Or some of the energy for latent heat is provided by the internal energy of the canister (1)		3



Question Number	Acceptable answers	Additional guidance	Mark
14(b)(i)	- Use of $V = \pi r^2 l$ - Use of $pV = NkT$ - Conversion of °C to K $N = 4.7 \times 10^{23}$	(1) <u>Example of calculation:</u> (1) $V = \pi \times 0.11^2 (\text{m})^2 \times 0.23(\text{m})$ $= 8.74 \times 10^{-3} \text{ m}^3$ (1) $T = 21^\circ\text{C} + 273 = 294 \text{ K}$ (1) $2.2 \times 10^5 \text{ Pa} \times 8.7 \times 10^{-3} \text{ m}^3 = N \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 294 \text{ K}$ $N = 4.74 \times 10^{23}$	4
14(b)(ii)	- Use of $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ - r.m.s. speed = 360 m s^{-1} Or - Use of $pV = \frac{1}{3} Nm \langle c^2 \rangle$ - r.m.s. speed = 360 m s^{-1} (ecf from (i))	(1) Give full credit if a mistake has been made calculating temperature in part (i) e.g if $T = 21^\circ\text{C}$ then r.m.s. speed = 95 m s^{-1} (1) Similarly for V <u>Example of calculation:</u> (1) $\frac{1}{2} \times 9.6 \times 10^{-26} \text{ kg} \langle c^2 \rangle = \frac{3}{2} 1.38 \times 10^{-23} \text{ J K}^{-1} \times 294 \text{ K}$ (1) $\langle c^2 \rangle = 127000 \text{ m}^2 \text{ s}^{-2}$ r.m.s. speed = 356 m s^{-1} Alternative: $2.2 \times 10^5 \text{ Pa} \times 8.7 \times 10^{-3} \text{ m}^3 = \frac{1}{3} 4.7 \times 10^{23} \times 9.6 \times 10^{-26} \text{ kg} \langle c^2 \rangle$ r.m.s. speed = 360 m s^{-1}	2

(Total for Question 14 = 9 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)	- The ammeter should be in series with the heater Or ammeter is not measuring current through the heater (1) - The range of the ammeter (mA) is too small (1)		2
3(b)(i)	- Both axes labelled (1) - Straight line with negative gradient (1) - Reading on balance does not cut the time axis (1)	MP3 dependent upon MP2 <u>Example of graph</u> 	3
3(b)(ii)	- Use of $W = VIt$ (1) - Use of $\Delta E = mL$ (1) $L = 2.4 \times 10^6 \text{ J kg}^{-1}$ (1)	<u>Example of calculation</u> $W = 12 \text{ V} \times 4.2 \text{ A} \times (6 \times 60)\text{s} = 1.81 \times 10^4 \text{ J}$ $L = \frac{1.81 \times 10^4 \text{ J}}{7.5 \times 10^{-3} \text{ kg}} = 2.41 \times 10^6 \text{ J kg}^{-1}$	3
3(b)(iii)	An explanation that makes reference to the following points: - Energy is transferred (from the beaker/heater/water) to the surroundings (1) - So the calculated value of L will be larger than the true value (1)		2

(Total for Question 3 = 10 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
19(a)	- Use of $\rho = \frac{m}{V}$ and volume of a cuboid (1) $m = 2.21 \times 10^5$ (kg) (1)	<u>Example of calculation</u> $V = 25.0 \text{ m} \times 3.10 \text{ m} \times 3.10 \text{ m} = 240 \text{ m}^3$ $m = 920 \text{ kg m}^{-3} \times 240 \text{ m}^3 = 2.21 \times 10^5 \text{ kg}$	2
19(b)(i)	- Use of $I = \frac{P}{A}$ (1) - Use of $E = mL$ (1) - Use of $E = mc\Delta\theta$ (1) - Use of 1% (1) - Use of $P = \frac{W}{t}$ (1) - Energy needed ($8.3 \times 10^8 \text{ J}$) is greater than energy arriving ($5.6 \times 10^8 \text{ J}$), so claim is incorrect. (ecf for mass from (a)) (1) Or $t = 18 \text{ hours} > 12 \text{ hours}$, so claim is incorrect (1)	<u>Example of calculation</u> $P = 1350 \text{ W m}^{-2} \times (3.1 \text{ m})^2 = 13\,000 \text{ W}$ $E = 0.01 \times 2.21 \times 10^5 \times 2.09 \times 10^3 \text{ J kg}^{-1}\text{K}^{-1} \times 20\text{K} = 9.24 \times 10^7 \text{ J}$ $E = 0.01 \times 2.21 \times 10^5 \text{ kg} \times 3.34 \times 10^5 \text{ J kg}^{-1} = 7.38 \times 10^8 \text{ J}$ $E_{\text{total}} = 8.31 \times 10^8 \text{ J}$ $t = \frac{8.31 \times 10^8 \text{ J}}{13\,000 \text{ W}} = 6.39 \times 10^4 \text{ s}$ $t = \frac{6.39 \times 10^4 \text{ s}}{3600 \text{ s hour}^{-1}} = 18 \text{ hours}$ For MP6 allow their value compared to the reference value.	6
19(b)(ii)	MAX 2 - Energy will transfer to the ice sculpture from the surroundings (1) - Radiation from the sun is not continuously incident on the statue (1) - The Sun will not always be directly overhead (1) - Some incident radiation will be reflected (1)	Accept the model is idealised, as sculpture is not cuboid	2

(Total for Question 19 = 10 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
6(a)	- Series circuit with power supply, heater and ammeter. (1) - Voltmeter connected in parallel with heater (1)		2
6(b)	- Use of $P = VI$ (1) - Calculation of gradient (1) - Gradient = $\frac{\Delta m}{\Delta t}$ (1) - Use of $\Delta E = mL$ and $P = \frac{\Delta E}{\Delta t}$ (1) $L = 2.30 \times 10^6 \text{ (J kg}^{-1}\text{)}$ (1) - Comparison of calculated value for L with values in table and appropriate conclusion. (1) - But not all of the energy supplied to the liquid will be used to boil the liquid Or thermal energy will be transferred to surroundings (1)	For MP2 and MP3 credit Δm read from graph and used with corresponding Δt value For MP3 and MP4, credit $L = \frac{VI}{\text{gradient}}$ Answers in the range $(2.26 - 2.34) \times 10^6 \text{ J kg}^{-1}$ <u>Example of calculation:</u> $\text{grad} = \frac{(211-155) \times 10^{-3} \text{ kg}}{(0-600) \text{ s}} = 9.33 \times 10^{-5} \text{ kg s}^{-1}$ $\therefore \frac{\Delta m}{\Delta t} = 9.33 \times 10^{-5} \text{ kg s}^{-1}$ $P = 20.5 \text{ V} \times 10.5 \text{ A} = 215 \text{ W}$ $\therefore L = \frac{215 \text{ W}}{9.33 \times 10^{-5} \text{ kg s}^{-1}} = 2.30 \times 10^6 \text{ J kg}^{-1}$	7



6(c)	• Use lagging to insulate the container from the surroundings (1) • So that a greater proportion of the energy supplied is used to boil the liquid (1) Or • Use a heater with a higher electrical power (1) • So that a shorter time is needed to boil the liquid (1)	Accept “to minimise heat loss to the surroundings”	2
------	--	--	---

(Total for Question 6 = 11 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)(i)	- Use of $P = VI$ (1) $P = 1900 \text{ W}$ (1.9 kW) (1)	<u>Example of calculation</u> $P = 230 \text{ V} \times 8.20 \text{ A} = 1890 \text{ W}$	2
8(a)(ii)	- Use of $\Delta E = mc\Delta\theta$ (1) - Use of $P = \frac{\Delta E}{\Delta t}$ (1) $\Delta t = 112 \text{ s}$ or 113 s ECF from (a)(i) (1)	<u>Example of calculation</u> $\Delta E = 0.655 \text{ kg} \times 4190 \text{ J kg}^{-1}\text{K}^{-1} \times (100 - 22.5)\text{K}$ $\Delta E = 2.13 \times 10^5 \text{ J}$ $\Delta t = \frac{2.13 \times 10^5 \text{ J}}{1890 \text{ W}} = 112.5 \text{ s}$	3
8(b)(i)	After a short time of boiling in the flask, all the apparatus would be at 100°C. Or so energy is not being used to heat up the flask Or so steam won't condense in the flask (1)		1
8(b)(ii)	- Use of $\Delta E = mL$ (1) - Use of $P = \frac{\Delta E}{\Delta t}$ (1) 1720 W (1.72 kW) (1)	<u>Example of calculation</u> $\frac{\Delta m}{\Delta t} = \frac{95 \times 10^{-3} \text{ kg}}{125 \text{ s}} = 7.6 \times 10^{-4} \text{ kg s}^{-1}$ $\frac{\Delta E}{\Delta t} = 7.6 \times 10^{-4} \text{ kg s}^{-1} \times 2.26 \times 10^6 \text{ J kg}^{-1}$ $P = 1720 \text{ J s}^{-1}$	3
8(b)(iii)	- Comparison of answer to (a)(i) with answer to (b)(ii) (1) - Not all of the energy from the heater is used to turn water from liquid state into vapour Or energy is being used to heat the heat exchanger Or not all the steam condenses in the heat exchanger (1) - Some energy is transferred to the surroundings (1)	e.g. rate at which thermal energy is supplied to the water in the flask is greater than rate at which thermal energy is removed from the water in the heat exchanger. If answer for (b)(ii) is bigger than 2 kW, 1 mark for correct comparison can be scored.	3
8(c)	By lagging the flask (to reduce energy transfer to the surroundings) (1)		1

(Total for Question 8 = 13 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
12(a)(i)	EITHER - Calculation of mean t (1) - Use of $s = ut$ (1) - Use of $v = \frac{2r^2 g(\rho_B - \rho_C)}{9\eta}$ (1) - Cocoa content = 30% Or viscosity at 35% = 4.5 (Pa s) (1) - Conclusion consistent with their graph value (1) OR - Viscosity at 35% = 4.5 (Pa s) (1) - Use of $v = \frac{2r^2 g(\rho_B - \rho_C)}{9\eta}$ (1) - Use of $s = ut$ to calculate time to fall T_{fall} (1) - Calculation of mean t (1) - Conclusion consistent with calculated value of T_{fall} (1)	<u>Example of calculation</u> $t = \frac{(9.6 + 9.9 + 9.6) \text{ s}}{3} = 9.7 \text{ s}$ $v = \frac{0.225 \text{ m}}{9.7 \text{ s}} = 0.0232 \text{ m s}^{-1}$ $\eta = \frac{2 \times (4.25 \times 10^{-3} \text{ m})^2 \times 9.81 \text{ m s}^{-2} \times (7750 - 1330) \text{ kg m}^{-3}}{9 \times 0.0232 \text{ m s}^{-1}}$ $\eta = 10.9 \text{ Pa s, so cocoa content is 30% (from graph)}$ Cocoa content is 30% so not consistent Or viscosity value is 4.5 Pa s so not consistent Time taken would be 4.0 s so not consistent with mean time	5

(Total for Question 12 = 13 marks)

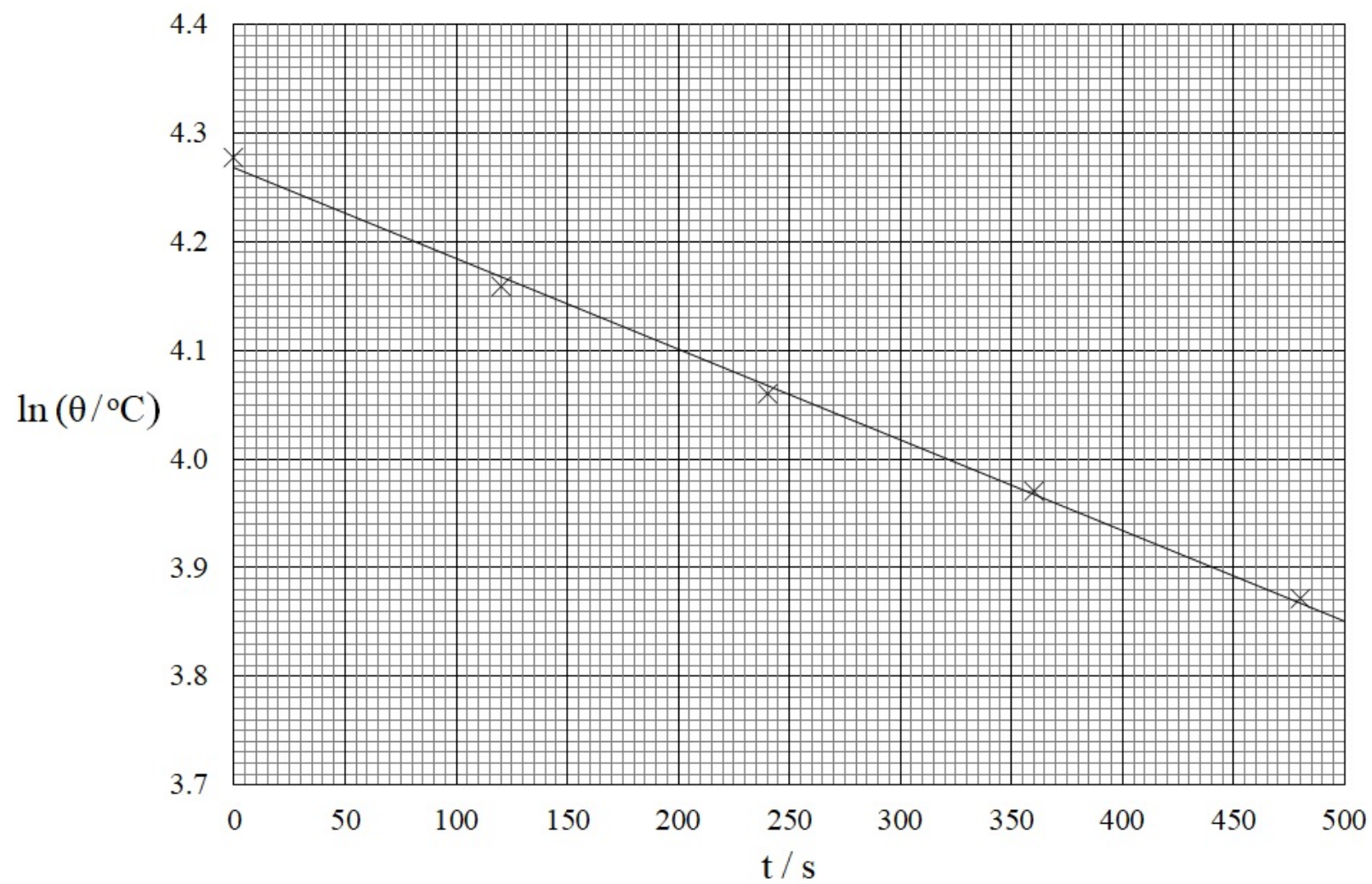


Question Number	Acceptable Answer		Additional Guidance													
8(a)	An explanation that makes reference to the following points: - Shows expansion $\ln \Delta\theta = \ln \Delta\theta_0 - bt$ - Compares with $y = mx + c$ and states that the gradient is b (which is constant)	(1) (1)		2												
8(b)(i)	- ln values correct (at least 2 dec.places) - Labels and unit - Scales - Plots - Line of best fit	(1) (1) (1) (1) (1)	<table><tr><th>$\Delta\theta / ^\circ\text{C}$</th><th>$\ln (\Delta\theta / ^\circ\text{C})$</th></tr><tr><td>72</td><td>4.277</td></tr><tr><td>64</td><td>4.159</td></tr><tr><td>58</td><td>4.060</td></tr><tr><td>53</td><td>3.970</td></tr><tr><td>48</td><td>3.871</td></tr></table>	$\Delta\theta / ^\circ\text{C}$	$\ln (\Delta\theta / ^\circ\text{C})$	72	4.277	64	4.159	58	4.060	53	3.970	48	3.871	5
$\Delta\theta / ^\circ\text{C}$	$\ln (\Delta\theta / ^\circ\text{C})$															
72	4.277															
64	4.159															
58	4.060															
53	3.970															
48	3.871															
8(b)(ii)	- Determines gradient using large triangle $b = 8 \times 10^{-4} \rightarrow 9 \times 10^{-4}$ (2 or 3 sf) - Units s^{-1}	(1) (1) (1)	<u>Example of calculation:</u> $m = \frac{4.27 - 3.85}{(0 - 500) \text{ s}} = 8.4 \times 10^{-4} \text{ s}^{-1}$	3												

8(c)	MAX 3 from • Dataloggers are useful when data changes over a very short (or very long) time scale • Dataloggers are useful when a number of quantities are being measured simultaneously • A comment on the time between temperature readings in this experiment. • It takes longer for the liquid in glass thermometer to respond to temperature changes than the temperature sensor • There may be parallax error in reading from the liquid in glass thermometer • Conclusion consistent with discussion of suitability of using a data logger	(1) (1) (1) (1) (1) (1)		4
------	--	---	--	----------

(Total for Question 8 = 14 marks)





Question Number	Acceptable Answer				Additional Guidance	Mark																																																					
*4	<table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table> Indicative content: IC1 The rate of decay depends upon the number of unstable nuclei in the sample ($A = -\lambda N$) IC2 Radium has a large half-life, so unstable nuclei are present in the sample for a long time IC3 When a nucleus decays there is a (small) decrease in mass Δm IC4 Energy is released according to $\Delta E = c^2 \Delta m$ IC5 Δm is small but c is large, so a significant amount of energy is released IC6 Energy released by the decay becomes kinetic energy of the atoms in the sample (hence sample is above the temperature of the surroundings)				IC points	IC mark	Max linkage mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully sustained reasoning. Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The table shows how the marks should be awarded for indicative content and structure and lines of reasoning. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> IC2: accept idea that it takes a long time to decay for “unstable nuclei are present...or a long period of time” IC3 accept a reference to binding energy increasing		Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	
IC points	IC mark	Max linkage mark	Max final mark																																																								
6	4	2	6																																																								
5	3	2	5																																																								
4	3	1	4																																																								
3	2	1	3																																																								
2	2	0	2																																																								
1	1	0	1																																																								
0	0	0	0																																																								
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																																																										
6	4																																																										
5–4	3																																																										
3–2	2																																																										
1	1																																																										
0	0																																																										
	Number of marks awarded for structure of answer and sustained line of reasoning																																																										
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																																																										
Answer is partially structured with some linkages and lines of reasoning	1																																																										
Answer has no linkages between points and is unstructured	0																																																										

6

(Total for Question 4 = 6 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
21(a)	The temperature at which the (mean) molecular kinetic energy is zero (1)	Accept The lowest temperature possible	1
21(b)	An explanation that makes reference to the following points: - The peak of the curve is higher (1) - The rate at which energy is radiated is proportional to temperature to the power of 4. (1) - The peak of the curve is displaced to the left (1) - The wavelength at which maximum rate of energy radiated occurs is inversely proportional to the temperature (1)	MP1 and MP3 allow correct sketch on graph MP2 allow reference to Stefan's law MP4 allow reference to Wien's law	4
21(c)	- Use of $\lambda_{\max}T$ with data for one star (1) - Use of $\lambda_{\max}T$ with data for all three stars (1) - Statement that values are similar/constant for each star AND comparison with Wein's Law constant (1)	<u>Example of calculation</u> $\lambda_{\max}T = 132 \text{ nm} \times 21500 \text{ K} = 2.838 \times 10^6 \text{ nm K}$ $\lambda_{\max}T = 245 \text{ nm} \times 11600 \text{ K} = 2.842 \times 10^6 \text{ nm K}$ $\lambda_{\max}T = 287 \text{ nm} \times 9940 \text{ K} = 2.844 \times 10^6 \text{ nm K}$	3



21(d)	• Use of $L = 4\pi r^2 \sigma T^4$ • Luminosity and temperature of Sirius A read from graph • Use of Luminosity of Sirius A with luminosity of the Sun. • $\frac{r_{\text{Sirius A}}}{r_{\text{Sun}}} = 1.84$ Or $r = 1.28 \times 10^9 \text{ m}$ • Comparison between candidate's ratio and given ratio with valid conclusion Or Comparison between $2 \times r_{\text{Sirius}}$ and r_{Sun} with a valid conclusion	Example of calculation $L = 4\pi(6.96 \times 10^8 \text{ m})^2 \times 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times (5800)^4$ $\therefore L = 3.91 \times 10^{26} \text{ W}$ Luminosity of Sirius = $30 L_{\text{Sun}}$ and $T = 10\,000 \text{ K}$ $r = \sqrt{\frac{30 \times 3.91 \times 10^{26} \text{ W}}{4\pi \times 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4} \times (10\,000 \text{ K})^4}}$ $\therefore r = 1.28 \times 10^9 \text{ m}$ $\frac{r_{\text{Sirius A}}}{r_{\text{Sun}}} = \frac{1.28 \times 10^9 \text{ m}}{6.96 \times 10^8 \text{ m}} = 1.84$ $1.84 \approx 2$, therefore claim is correct	5
-------	---	---	---

(Total for Question 21 = 13 marks)



***12(a)**

This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.

Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.

The table shows how the marks should be awarded for indicative content and structure and lines of reasoning.

Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points
6	4
5-4	3
3-2	2
1	1
0	0

	Number of marks awarded for structure of answer and sustained line of reasoning
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkages between points and is unstructured	0

Indicative content:

1. As the temperature of the gas increases the (average) speed/ E_k of the atoms increases
2. Greater speed/ E_k so the momentum of the atoms increases
3. The rate/frequency of collision of atoms with the container walls increases **Or** the time between collisions with the walls decreases
4. The rate of change of momentum at the walls increases
5. Rate of change of momentum is equal to the force
6. Pressure is $\frac{\text{force}}{\text{area}}$ and the force (on the walls) is greater

IC Points	IC Mark	Max linkage mark avail.	Max final mark
6	4	2	6
5	3	2	5
4	3	1	4
3	2	1	3
2	2	0	2
1	1	0	1
0	0	0	0

IC3 and IC4 must include a mention of the walls/container

6

12(b)(i)	• Conversion of MeV to J (1) • See $Q_1 = 79 \times 1.6 \times 10^{-19}$ and $Q_2 = 2 \times 1.6 \times 10^{-19}$ (1) • Use of $V = \frac{Q}{4\pi\epsilon_0 r}$ and $W = QV$ (1) • $r = 4.1 \times 10^{-14}$ m (1)	<u>Example of calculation</u> $E_\alpha = 5.5 \times 10^6 \text{ eV} \times 1.6 \times 10^{-19} \text{ J eV}^{-1} = 8.8 \times 10^{-13} \text{ J}$ $8.8 \times 10^{-13} \text{ J} = \frac{79 \times 1.6 \times 10^{-19} \text{ C} \times 2 \times 1.6 \times 10^{-19} \text{ C}}{4\pi \times 8.85 \times 10^{-12} \text{ F m}^{-1} r}$ $r = \frac{3.64 \times 10^{-26} \text{ N m}^2}{8.8 \times 10^{-13} \text{ J}} = 4.1 \times 10^{-14} \text{ m}$	4
12(b)(ii)	• Electrons are behaving like waves (1) • wavelength = $\frac{h}{\text{momentum}}$ (1) • Electron wavelength must be similar to the atomic spacing in the foil (1)	MP3: Accept electron wavelength must be similar to the distance between (adjacent) nuclei	3
12(c)	• Electrons are excited to higher energy states / levels (by incident electrons) (1) • An electron returns to the lower energy state / level resulting in the emission of a <u>photon</u> (1) • The energy of the photon is equal to the difference of the energy states / levels (1) • Large difference in energy states / levels so as $E = hf$, radiation is high frequency (1)	For MP1 and MP2 allow • Electrons knock electrons out of low energy levels • Electrons cascade down to fill up the levels	4

(Total for Question 12 = 17 marks)



Question Number	Acceptable answers	Additional guidance	Mark
2	The only correct answer is D because pressure is proportional to absolute temperature and inversely proportional to volume, so the effect of the volume change is to increase the pressure by $3/2$ and the effect of the temperature change is to increase the pressure by $6/5$, and $18/10 = 9/5$ A is not correct because a pressure of $5/9 p$ would depend on pressure being proportional to volume and inversely proportional to absolute temperature rather than being proportional to absolute temperature and inversely proportional to volume B is not correct because this assumes that pressure is proportional to both volume and absolute temperature, giving an answer of $4/5 p$, instead of assuming that pressure is proportional to absolute temperature and inversely proportional to volume C is not correct because this assumes that pressure is inversely proportional to both volume and absolute temperature, giving an answer of $5/4 p$, instead of assuming that pressure is proportional to absolute temperature and inversely proportional to volume		1

Question Number	Acceptable answers	Additional guidance	Mark
18 (a)	- Use of $p = F/A$ (1) - Cylinder pressure = calculated pressure + atmospheric pressure (1) $p = 2.0 \times 10^5 \text{ Pa}$ (1)	<u>Example of calculation</u> $p = 8.8 \text{ N} / 9.2 \times 10^{-5} \text{ m}^2$ $= 9.57 \times 10^4 \text{ Pa}$ Total $p = 9.57 \times 10^4 \text{ Pa} + 1.0 \times 10^5 \text{ Pa} = 1.957 \times 10^5 \text{ Pa}$	3
18 (b)	- Use of $pV = NkT$ (1) $= 349 \text{ K} (= 76 \text{ }^\circ\text{C})$ (ecf from (a)) (1)	<u>Example of calculation</u> $pV/T = \text{constant}$ $T = 1.957 \times 10^5 \text{ Pa} \times 6.7 \times 10^{-6} \text{ m}^3 \times 292 \text{ K} /$ $1.0 \times 10^5 \text{ Pa} \times 1.1 \times 10^{-5} \text{ m}^3$ $= 349 \text{ K} = 76 \text{ }^\circ\text{C}$	2
18 (c)	- Equate $pV = NkT$ and $pV = \frac{1}{3}Nm \langle c^2 \rangle$ - Suitable algebra		2
18 (d)	- Use of $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ (1) $\sqrt{\langle c^2 \rangle} = 500 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ $\frac{1}{2} \times 4.8 \times 10^{-26} \text{ kg} \times \langle c^2 \rangle = \frac{3}{2} \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 292 \text{ K}$ $\langle c^2 \rangle = 2.52 \times 10^5 \text{ m}^2 \text{ s}^{-2}$ $\sqrt{\langle c^2 \rangle} = 502 \text{ m s}^{-1}$	2
(Total for Question 18 = 9 marks)			



Question Number	Acceptable Answer	Additional Guidance	Mark
4(a)	- Use of $V = \frac{4}{3}\pi r^3$ (1) - Use of $pV = NkT$ (1) - Temperature conversion to kelvin (1) - Use of $m = \frac{N}{6.02 \times 10^{23}} \times 4.00 \times 10^{-3} \text{ kg}$ (1) $m = 9.46 \times 10^{-3} \text{ kg}$ (1)	Allow MP2 if temperature not converted to K <u>Example of calculation</u> $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times (4.36 \times 10^{-2} \text{ m})^3 = 3.47 \times 10^{-4} \text{ m}^3$ $N = \frac{pV}{kT} = \frac{1.65 \times 10^7 \text{ Pa} \times 3.47 \times 10^{-4} \text{ m}^3}{1.38 \times 10^{-23} \text{ J K}^{-1} \times (18.5 + 273) \text{ K}}$ $\therefore N = 1.42 \times 10^{24}$ $m = \frac{1.42 \times 10^{24}}{6.02 \times 10^{23}} \times 4.00 \times 10^{-3} \text{ kg} = 9.46 \times 10^{-3} \text{ kg}$	5
4(b)	- Upthrust on canister equals weight of air/fluid displaced. (1) - Volume of canister stays constant, so upthrust on canister remains constant (and student X is incorrect) (1) - Mass of helium gas (in canister) decreases (1) - Hence the weight will decrease (as helium is released) and student Y is correct (1)		4

(Total for Question 4 = 9 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)(i)	MAX 3 - There is an inconsistent number of decimal places (1) - No evidence of repeats (1) - Range is too small (1) - Not enough readings between 24 °C and 60 °C (1) - Four (pairs of) readings are not enough (1)		3
11(a)(ii)	An explanation that makes reference to the following points: - The (trapped) air may not have been at the temperature of the water (1) - Because water temperature may not be uniform Or because transfer of thermal energy through the glass takes time (1) - The volume of the (trapped) air column may not be proportional to the length of the column (1) - Because the bore of the glass tube may not have been uniform (1) - The temperature / length may be read incorrectly (1) - Because there may be a parallax error when reading the temperature or length of the trapped air column (1)	Mark any two pairs	4



11(a)(iii)	Any two from: • Stir water in beaker (1) • Use digital thermometer Or temp sensor & data logger (1) • Put thermometer close to tube (1) • Let tube reach thermal equilibrium before taking readings (1) • Use thermostatically controlled water bath (1) • Take reading in line with scale (1)		2
11(b)(i)	An explanation that makes reference to the following points: • The intercept represents the temperature of the air at which the volume occupied would be zero (1) • This is the absolute zero (of temperature) (1) • Absolute zero is the lowest attainable temperature Or absolute zero is the temperature at which the atoms/molecules of the gas have zero kinetic energy (1)	For MP3 accept atoms/molecules stop moving	3
11(b)(ii)	MAX 4 Resolution: • It is correct that uncertainties would be reduced by using high resolution instruments (1) • But the instruments are not high resolution (1) • There could be a systematic error (in the measurements) (1) Graph: • The points do not lie on a perfect straight line Or the true relationship may not linear (1) • Temperature intercept may not be accurate Or there may be extrapolation errors (1) • More points are needed Or a wider range is needed (1)		4

(Total for Question 11 = 16 marks)



Question Number	Answers	Mark
7	The only correct answer is C <i>A is incorrect because the mean kinetic energy is constant at constant temperature</i> <i>B is incorrect because collisions between molecules do not increase the force on the walls of the container</i> <i>D is incorrect because the momentum change depends upon the root mean square speed of the molecules</i>	1



Question Number	Acceptable answers	Additional guidance	Mark
11(a)	- Equates right hand sides (1) - Final E_k formula ($\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$) and k is constant (1)		2
11(b)	- Use of $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ (1) - with T in Kelvin (1) $\sqrt{\langle c^2 \rangle} = 497 \text{ m s}^{-1}$ (1)	<u>Example of calculation</u> $\frac{1}{2} m \langle c^2 \rangle = \frac{3}{2} kT$ $\frac{1}{2} \times 5.0 \times 10^{-26} \text{ kg} \times \langle c^2 \rangle = \frac{3}{2} \times 1.38 \times 10^{-23} \text{ J K}^{-1} \times 298 \text{ K}$ $\langle c^2 \rangle = 247\,000 \text{ m}^2 \text{ s}^{-2}$ $\sqrt{\langle c^2 \rangle} = 497 \text{ m s}^{-1}$	3

(Total for Question 11 = 5 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark																																																				
*14	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning. <table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table> Indicative content: IC1 (Average) distance travelled by molecules between collisions with piston/walls decreases Or Time between collisions between molecules and the piston/walls decreases IC2 Rate/frequency of collision of molecules with piston/walls increases IC3 (Mean) velocity (of molecules) stays constant Or change in momentum per collision stays constant IC4 Rate of change of momentum (during collisions with piston) increases IC5 Force on piston/walls increases IC6 $p = F/A$ so pressure exerted (by gas) increases	IC points	IC mark	Max linkage mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative points seen in answer</th><th>Number of marks awarded for indicative points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5-4</td><td>3</td></tr><tr><td>3-2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><td></td><td>Number of marks awarded for structure and lines of reasoning</td></tr><tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkage between points and is unstructured</td><td>0</td></tr></table>	Number of indicative points seen in answer	Number of marks awarded for indicative points	6	4	5-4	3	3-2	2	1	1	0	0		Number of marks awarded for structure and lines of reasoning	Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkage between points and is unstructured	0	6
IC points	IC mark	Max linkage mark	Max final mark																																																				
6	4	2	6																																																				
5	3	2	5																																																				
4	3	1	4																																																				
3	2	1	3																																																				
2	2	0	2																																																				
1	1	0	1																																																				
0	0	0	0																																																				
Number of indicative points seen in answer	Number of marks awarded for indicative points																																																						
6	4																																																						
5-4	3																																																						
3-2	2																																																						
1	1																																																						
0	0																																																						
	Number of marks awarded for structure and lines of reasoning																																																						
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2																																																						
Answer is partially structured with some linkages and lines of reasoning	1																																																						
Answer has no linkage between points and is unstructured	0																																																						

(Total for Question 14 = 6 marks)



Question Number	Acceptable Answer	Additional Guidance	Mark																																																				
*6	This question assesses a student’s ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning. Indicative content: IC1 Average kinetic energy of (air) molecules decreases IC2 So the (mean square) speed/velocity (of air molecules) decreases Or So the momentum (of air molecules) decreases IC3 Rate of collision with container walls decreases Or Momentum change in each collision with container walls decreases IC4 Rate of change of momentum (with container walls) decreases IC5 So force (on container walls) decreases IC6 $P = F/A$ so pressure (exerted by air molecules) decreases	Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning <table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	IC points	IC mark	Max linkage mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	6
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																																																						
6	4																																																						
5–4	3																																																						
3–2	2																																																						
1	1																																																						
0	0																																																						
	Number of marks awarded for structure of answer and sustained line of reasoning																																																						
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																																																						
Answer is partially structured with some linkages and lines of reasoning	1																																																						
Answer has no linkages between points and is unstructured	0																																																						
IC points	IC mark	Max linkage mark	Max final mark																																																				
6	4	2	6																																																				
5	3	2	5																																																				
4	3	1	4																																																				
3	2	1	3																																																				
2	2	0	2																																																				
1	1	0	1																																																				
0	0	0	0																																																				

(Total for Question 6 = 6 marks)



Question Number	Acceptable answers	Additional guidance	Mark																																																				
19 (a)	- Use of $V = \frac{4}{3}\pi \left(\frac{d}{2}\right)^3$ (1) - Use of $pV = NkT$ (1) - Conversion of temperature to kelvin (1) $N = 6.5 \times 10^{17}$ (1)	<u>Example of calculation:</u> $V = \frac{4}{3}\pi(0.080 \text{ m})^3 = 2.14 \times 10^{-3} \text{ m}^3$ $N = \frac{1.25 \text{ Pa} \times 2.14 \times 10^{-3} \text{ m}^3}{1.38 \times 10^{-23} \text{ N m K}^{-1} \times (273 + 25)\text{K}} = 6.50 \times 10^{17}$	4																																																				
*19 (b)	This question assesses a student’s ability to show a coherent and logically structured answer with linkages and fully-sustained reasoning. Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning <table><tr><th>IC points</th><th>IC mark</th><th>Max structure mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table>	IC points	IC mark	Max structure mark	Max final mark	6	4	2	6	5	3	2	5	4	3	1	4	3	2	1	3	2	2	0	2	1	1	0	1	0	0	0	0	Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning. The following table shows how the marks should be awarded for indicative content. <table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table> <table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table> IC5 and IC6 can be awarded if suitable equations with terms explained are used	Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points	6	4	5–4	3	3–2	2	1	1	0	0		Number of marks awarded for structure of answer and sustained line of reasoning	Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2	Answer is partially structured with some linkages and lines of reasoning	1	Answer has no linkages between points and is unstructured	0	6
IC points	IC mark	Max structure mark	Max final mark																																																				
6	4	2	6																																																				
5	3	2	5																																																				
4	3	1	4																																																				
3	2	1	3																																																				
2	2	0	2																																																				
1	1	0	1																																																				
0	0	0	0																																																				
Number of indicative marking points seen in answer	Number of marks awarded for indicative marking points																																																						
6	4																																																						
5–4	3																																																						
3–2	2																																																						
1	1																																																						
0	0																																																						
	Number of marks awarded for structure of answer and sustained line of reasoning																																																						
Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout	2																																																						
Answer is partially structured with some linkages and lines of reasoning	1																																																						
Answer has no linkages between points and is unstructured	0																																																						



	Indicative content IC1 Electrons in neon atoms/molecules absorb <u>energy</u> due to electron collisions Or neon atoms/molecules absorb <u>energy</u> due to electron collisions IC2 Electrons in neon atoms/molecules move to higher energy levels/states Or Electrons in neon atoms/molecules are excited Or Neon atoms/molecules are excited IC3 A <u>photon</u> is released when an electron drops down energy levels Or A <u>photon</u> is released when an atoms/electron de-excites IC4 Electrons/atoms/molecules have discrete energy levels/states IC5 Frequency/wavelength (of emitted photon) is determined by difference in energy levels/states Or $E_2 - E_1 = hf$ where f is frequency IC6 Limited number of possible energy levels/states, and so only certain/particular/specific frequencies/ wavelengths are emitted Or Only certain energy changes possible, and so only certain/particular/specific frequencies/ wavelengths are emitted		
--	---	--	--

(Total for Question 19 = 10 marks)



Question Number	Acceptable answers	Additional guidance	Mark
17(a)	- Use of $pV = NkT$ (1) - Conversion of T in K (1) - Use of $\rho = m/V$ to determine mass of air in the balloon (1) - Calculation of total mass = mass of air at 120 °C + passengers + balloon (1) - Use of $W = mg$ (1) $W = 31\,600\text{ N}$, which is less than $33\,000\text{ N}$, so the balloon can take off (1)	<u>Example of calculation</u> $p_1 V_1 = NkT_1$ $p_1 V_1 / T_1 = NkT_2 = p_2 V_2 / T_2$ $V_1 / 293\text{ K} = 2800\text{ m}^3 / 393\text{ K}$ Volume of gas before heating, $V_1 = 2087\text{ m}^3$ mass of air in balloon $= 1.2\text{ kg m}^{-3} \times 2087\text{ m}^3$ $= 2505\text{ kg}$ Total mass with 5 passengers $= (2505 + 340 + 380)\text{ kg} = 3225\text{ kg}$ $W = 3225\text{ kg} \times 9.81\text{ N kg}^{-1} = 31\,637\text{ N}$ $31\,600\text{ N} < 33\,000\text{ N}$	6
17(b)(i)	Any one from: - Point particles - Particles have negligible volume (compared to their container) - Negligible forces between particles (except during a collision) - Range of molecular forces small (in comparison to average separation) - Duration of collisions negligible (in comparison to time between them) - Newtonian mechanics applies - Particles moves with uniform velocity between collisions - Elastic collisions - Particles move with (constant) random motion (1)	Accept molecules for particles	1



17(b)(ii)	- States $pV = NkT$ or $pV = 1/3 Nm\langle c^2 \rangle$ (1) - Suitable algebra to show $\frac{1}{2} m\langle c^2 \rangle = 3/2 kT$ (1)		2
17(b)(iii)	- Use of a.m.u. to determine particle mass (1) - Use of $\frac{1}{2} m\langle c^2 \rangle = 3/2 kT$ with T in K (1) - rms speed = 590 m s⁻¹ (1)	<u>Example of calculation</u> Mass = $28 \times 1.66 \times 10^{-27}$ kg = 4.65×10^{-26} kg $\frac{1}{2} \times 4.65 \times 10^{-26}$ kg $\langle c^2 \rangle = 3/2 \times 1.38 \times 10^{-23}$ J K ⁻¹ $\times$ 393 K $c = \sqrt{349900} = 590$ m s ⁻¹	3

(Total for Question 17 = 12 marks)

