1 A small amount of copper is heated in a container. The copper starts to melt.

Which statement about the melting of copper is correct?

A Temperature is constant and the kinetic energy of the copper atoms increases.
B Temperature increases and the potential energy of the copper atoms increases.
C Temperature is constant and the potential energy of the copper atoms increases.
D Temperature increases and the kinetic energy of the copper atoms increases.

Your answer

[1]

2 What is the correct unit for specific heat capacity?

A $m^2s^{-2}K^{-1}$
B $ms^{-2}K^{-1}$
C $m^2s^{-1}K^{-1}$
D $m^2s^{-2}K$

Your answer

[1]

3 The volume of a fixed mass of an ideal gas is *V*. The gas exerts pressure *p* and has thermodynamic temperature *T*. The temperature of the gas is now increased to 2*T*. The new pressure exerted by the gas is 3*p*.

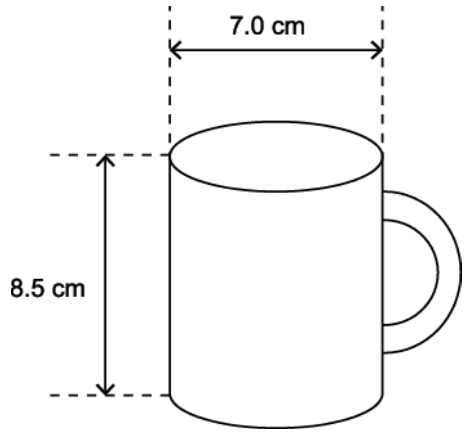
What is the new volume of the gas in terms of *V*?

A $\frac{1}{6}V$
B $\frac{2}{3}V$
C $\frac{3}{2}V$
D $6V$

Your answer

[1]

4(a) A cylindrical cup of internal diameter 7.0 cm and height 8.5 cm is filled to the top with water.



The density of water is 1000 kg m^{-3}. The mass of one mole of water is 18 g. The specific heat capacity of water is 4200 J kg^{-1} K^{-1}.

Calculate the number of water molecules in the cup.

number of molecules =______________ **[2]**

(b) Show that the minimum time taken for a 0.50 kW camping kettle to bring a cup of water at 20 °C to boiling point is about 200 s.

[3]

(c) In a laboratory test, the camping kettle was found to bring a cup of water to the boil in 320 seconds.

Explain why your previous answer is an underestimate and suggest **two** ways that you can refine the test to ensure that the time to boil is closer to 200 s.

-- [3]

5(a) Brownian motion is often demonstrated by observing the microscopic motion of smoke particles suspended in air.

State the observation and conclusion associated with this Brownian motion.

--- [2]

(b) Brownian motion provides evidence for a kinetic model of gases.
State **three** key assumptions made in the kinetic theory of gases .

--- [3]

(c) A gas is at a temperature of 20°C. The mass of each molecule is 4.7×10^{-26} kg.

(i) Show that the root mean square (r.m.s.) speed the gas molecules is about 500 m s^{-1}.

[3]

(ii) A gas molecule makes a head-on collision with a **stationary** smoke particle. Fig. 20 shows the gas molecule and the smoke particle before and after the collision. The final speed of the smoke particle is 23 m s^{-1}.

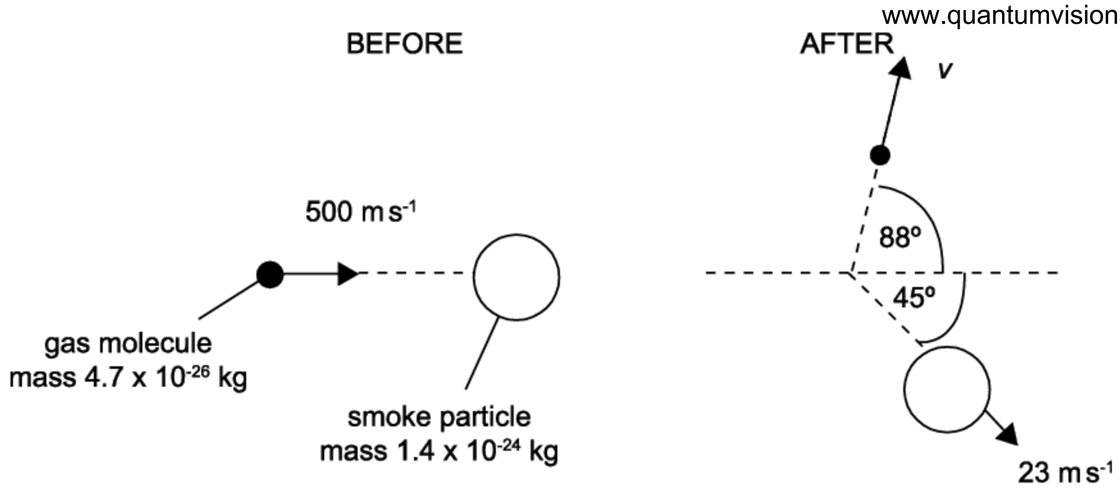


Fig. 20

1 State and explain the **total** momentum of the molecule and smoke particle after the collision in a direction perpendicular to initial velocity of the gas molecule.

____

____

____ **[2]**

2 Calculate the speed v of the gas molecule after the collision.

v = ____________________ $m\ s^{-1}$ **[2]**

6(a) The apparatus shown in **Fig. 20.1** is used to investigate the variation of the product *PV* with temperature in the range 20 °C to 100 °C. The pressure exerted by the air is *P* and the volume of air inside the flask is *V*.

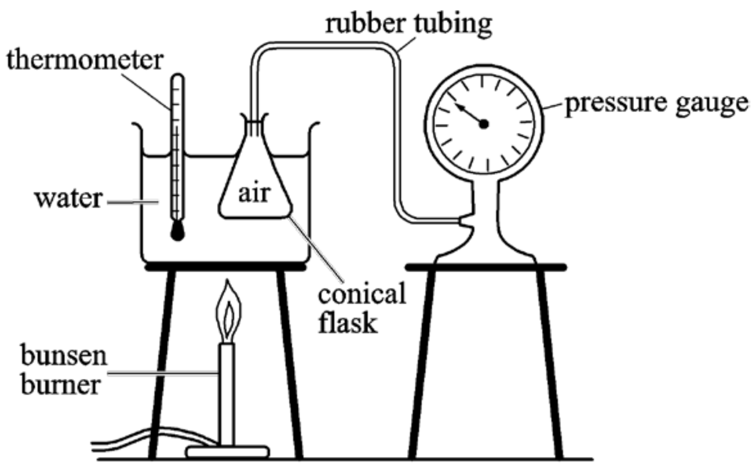


Fig. 20.1

Describe how this apparatus can be set up and used to ensure accurate results.

[4]

(b) An investigation similar to that shown in **Fig. 20.1** gives measurements of the pressure *P*, volume *V* and temperature *θ* in degrees Celsius of a fixed mass of gas.

The results are used to plot the graph of *PV* against *θ* shown in **Fig. 20.2**.

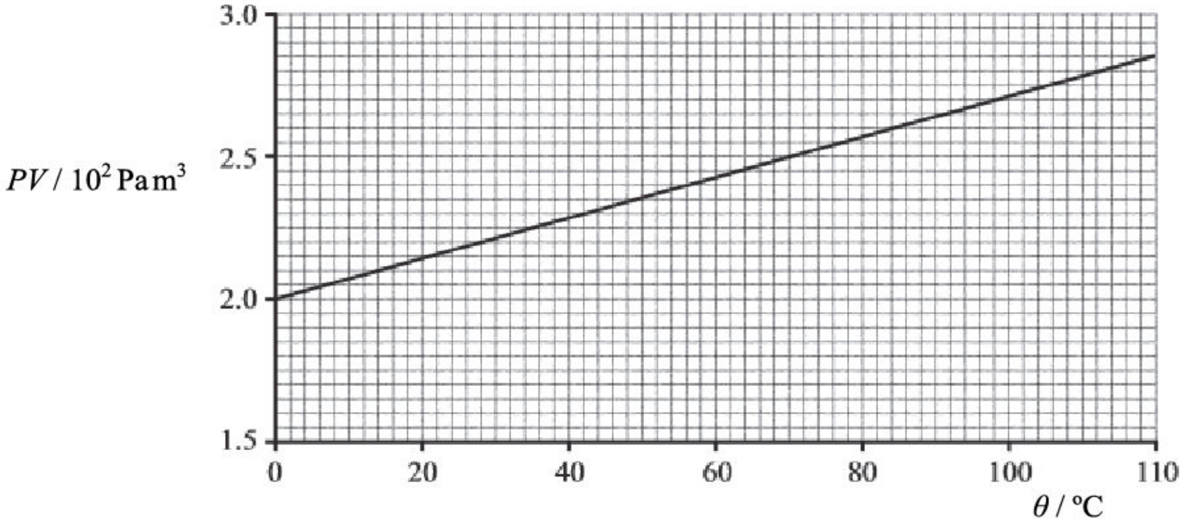


Fig. 20.2

(i) Explain, in terms of the motion of particles, why the graph does **not** go through the origin.

____

____

____ **[2]**

(ii) The mass of a gas particle is 4.7×10^{-26} kg. Use the graph in **Fig 20.2** to calculate

1 the mass of the gas

mass = _______________ kg

2 the internal energy of the gas at a temperature of 100 °C.

internal energy = _______________ J **[4]**

7(a) Fig. 6.1 shows how the volume *V* of a fixed mass of an ideal gas at constant pressure varies with temperature θ from 0 °C to 120 °C.

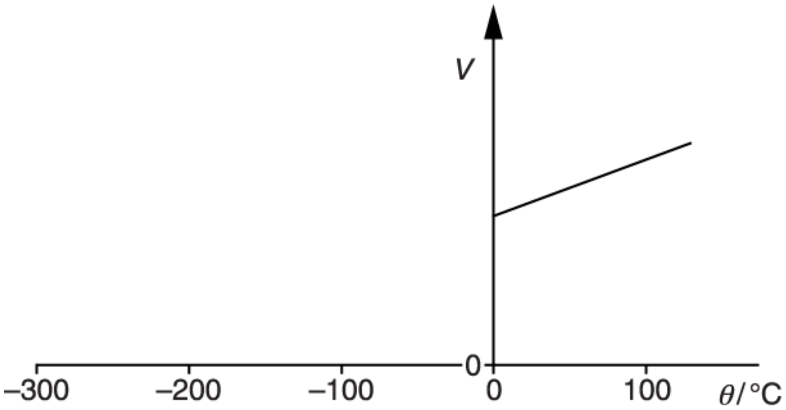


Fig. 6.1

Describe how this graph leads to the concept of an absolute zero of temperature.

--- [2]

(b) A mass of gas is enclosed in a tank. The gas is cooled until it becomes a liquid. During this process its internal energy changes.

(i) State what is meant by the *internal energy* of the gas.

--- [1]

(ii) Explain why the internal energy of the gas differs from that of its liquid phase.

--- [2]

(c) A scuba diver uses air in which the percentage of nitrogen is reduced by adding helium to form a substance known as Trimix. A 1.2×10^{-2} m^3 rigid steel scuba diving tank contains 45 mol of air at a temperature of 20 °C.

(i) Calculate the pressure in the tank.

pressure = ______________________________ Pa **[2]**

(ii) The tank is then connected to a cylinder of volume 2.0×10^{-3} m^3 containing helium at a pressure of 5.0×10^7 Pa and a temperature of 20 °C as shown in Fig. 6.2.

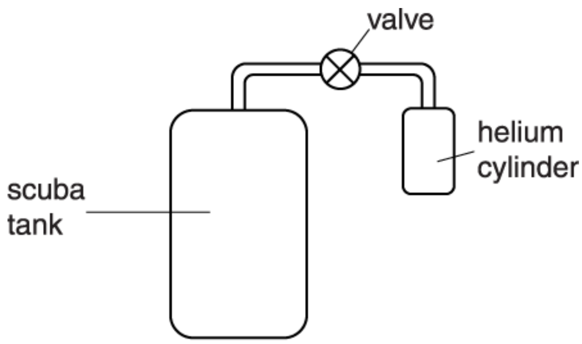


Fig. 6.2

The valve is opened allowing the gases to mix. When mixed the final temperature is 20 °C. Calculate the final pressure of the resulting Trimix in the scuba tank helium cylinder system.

pressure = ______________________________ Pa **[3]**

(iii) Explain why you would expect this pressure to decrease when the tank is used by a diver in water where the temperature is 4 °C.

____

____

____ **[1]**

8 For a fusion reaction to occur the separation between the deuterium and tritium nuclei must be less than 10^{-14} m. This means that the average kinetic energy of these hydrogen nuclei needs to be about 70 keV. The energy released by the fusion reaction is 18 MeV.

(i) Calculate the repulsive electrical force between the deuterium and tritium nuclei at a separation of 10^{-14} m.

force = ____________________________ N **[2]**

(ii) Assume that a mixture of these hydrogen nuclei behaves as an ideal gas.

Estimate the temperature of the mixture of nuclei required for this fusion reaction.

temperature = ____________________________ K **[3]**

(iii) In practice, fusion occurs at a much lower temperature. Suggest a reason why.

____

____

____

____ **[1]**

(iv) Calculate the change in mass in a single fusion reaction.

change in mass = ____________________________ kg **[2]**

(v) Fig. 3.1 shows the variation of probability of fusion reaction with temperature *T* for deuterium and tritium and for deuterium and helium.

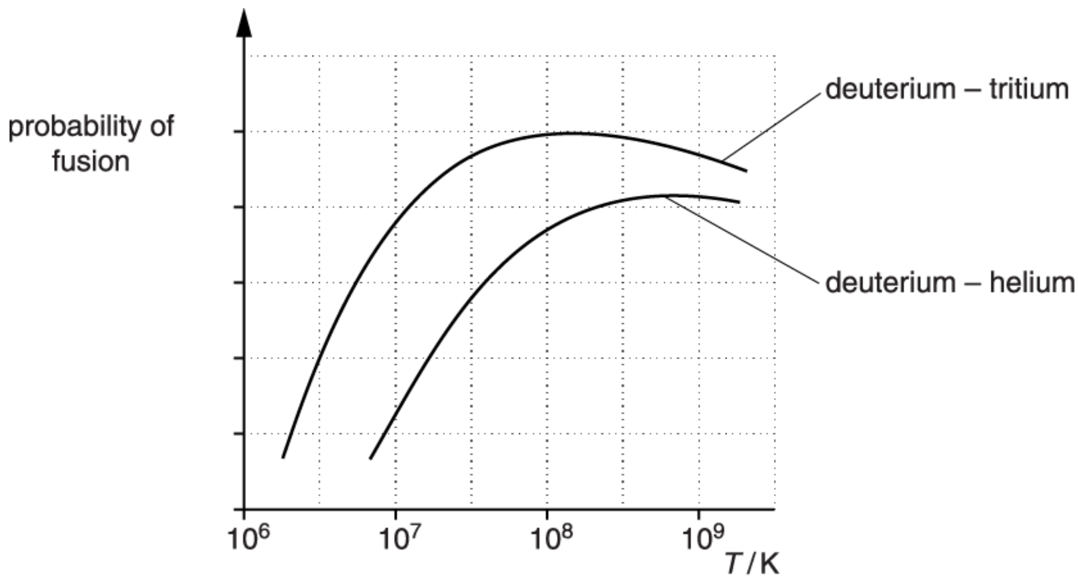


Fig. 3.1

Suggest why the probability of reaction at a given temperature is smaller for deuterium and helium.

____

____

____

____

____

____ **[2]**

9 Fig. 4.1 shows a circuit with a capacitor of capacitance 0.010 F.

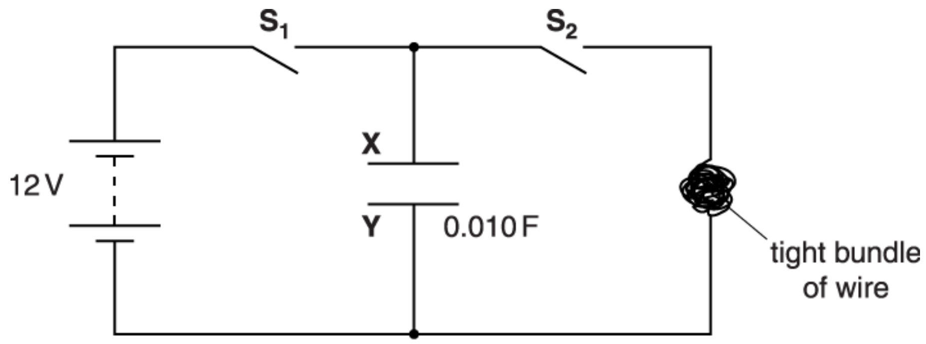


Fig. 4.1

A tight bundle of wire is made from 5.0 m of insulated wire of diameter 0.12 mm and resistivity 4.9×10^{-7} Ω m. The material of the wire has density 8900 kg m^{-3} and specific heat capacity 420 J kg^{-1} K^{-1}.

(i) Calculate the time constant of the circuit.

time constant = ______________________________ s **[3]**

(ii) Switch S_2 is open. Switch S_1 is closed. Explain in terms of the movement of electrons how **X** and **Y** acquire equal but opposite charge.

____

____

____

____

____

____

____

____ [3]

(iii) Switch S_1 is opened. The potential difference across the capacitor is 12V. Switch S_2 is now closed. Assume that all the energy stored by the capacitor is used to heat up the bundle of wire. Calculate the increase in the temperature of the bundle of wire.

increase in temperature = ____________________________ °C **[4]**

(iv) State and explain how your answer to **(iii)** would change when a 24V power supply is used to carry out the experiment.

____

____

____

____ [2]

10 The fusion of helium nuclei to make heavier elements occurs in red giants at temperatures above 10^8 K.

Estimate the mean speed of helium nuclei at a temperature of 10^8K.

mass of helium nucleus = 6.6×10^{-27} kg

speed = ______________________________ ms^{-1} **[2]**

11 An X-ray tube operates using a 150 kV supply. X-ray photons are produced inside the tube when a beam of high-speed electrons accelerated from the cathode collide with the metal anode. About 99% of the total kinetic energy of the electrons at the anode is converted into heat energy which heats the anode. The remaining energy is transformed into the energy of the X-ray photons.

The current in the electron beam between the cathode and the anode is 4.8 mA.

(i) Show that the number of electrons incident at the anode per second is $3.0 \times 10^{16}\ s^{-1}$.

[1]

(ii) The anode is made from metal of specific heat capacity 140J $kg^{-1}\ K^{-1}$. It has a mass of 8.6 g. The X-ray tube is switched on. Calculate the initial rate of increase of temperature of the anode.

rate of temperature increase = _____________________________ °C s^{-1} **[3]**

(iii) A single electron is responsible for producing an X-ray photon. Calculate the shortest wavelength of the X-rays produced from the X-ray tube.

wavelength = ______________________________ m **[2]**

12 You are provided with a small bottle of cooking oil and standard physics laboratory equipment. With the help of a **labelled** diagram, describe an electrical experiment to determine the specific heat capacity *c* of the oil.
State **two** sources of uncertainty in your measurements and discuss how these could be reduced.

In your answer, you should use appropriate technical terms spelled correctly.

[6]

13(a) Fig. 6.1 shows the apparatus used to observe Brownian motion using pollen grains suspended in a liquid.

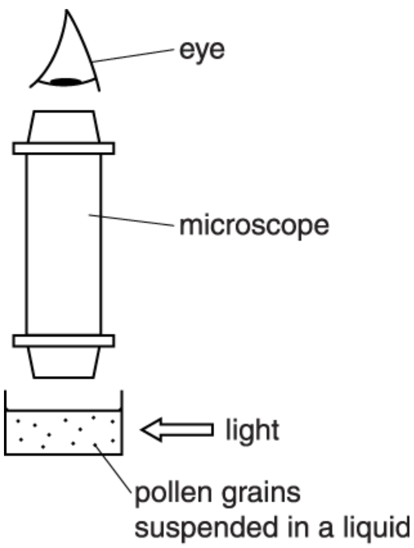


Fig. 6.1

(i) State **two** conclusions that may be deduced about the molecules of the liquid from the motion of the pollen grains observed with the microscope.

____

____

____

____ [2]

(ii) Suggest how the motion of these pollen grains could be increased.

____

____

____ [1]

(b)

(i) State **three** assumptions made in the development of the kinetic model of an ideal gas.

In your answer, you should use appropriate technical terms spelled correctly.

[3]

(ii) Use the kinetic model of a gas and Newton's laws of motion to explain how a gas exerts a pressure on the walls of its container.

[4]

(c) The ideal gas equation is $pV = nRT$.

Show that the pressure p exerted by a fixed mass of gas is given by the equation

$$p = \frac{\rho RT}{M}$$

where ρ is the density of the gas and M is the mass of one mole of gas.

[3]

(d) The Earth's atmosphere may be treated as an ideal gas whose density, pressure and temperature all decrease with height.

In 1924, Howard Somervell and Edward Norton set a new altitude record when attempting to climb Mount Everest. They managed to climb to a vertical height of 8570 m above sea level by breathing in natural air. At this height, the air pressure was 0.35 times the pressure at sea level and the temperature was -33 °C. At sea level, air has a temperature 20 °C and density 1.3 kg m^{-3}.

(i) Calculate the density of the air at a height of 8570 m at the time the record was set.

density = _____________________________ kg m^{-3} **[3]**

(ii) Determine the ratio

$$\frac{\text{number of air molecules present in Somervell's lungs at the top of his climb}}{\text{number of air molecules present in Somervell's lungs at sea level}}.$$

Assume that the volume of Somervell's lungs remained constant throughout the climb.

ratio = ______________________________ **[2]**

[Total: 18]

14 This question is about the operation of an electrically powered shower designed by an electrical firm.

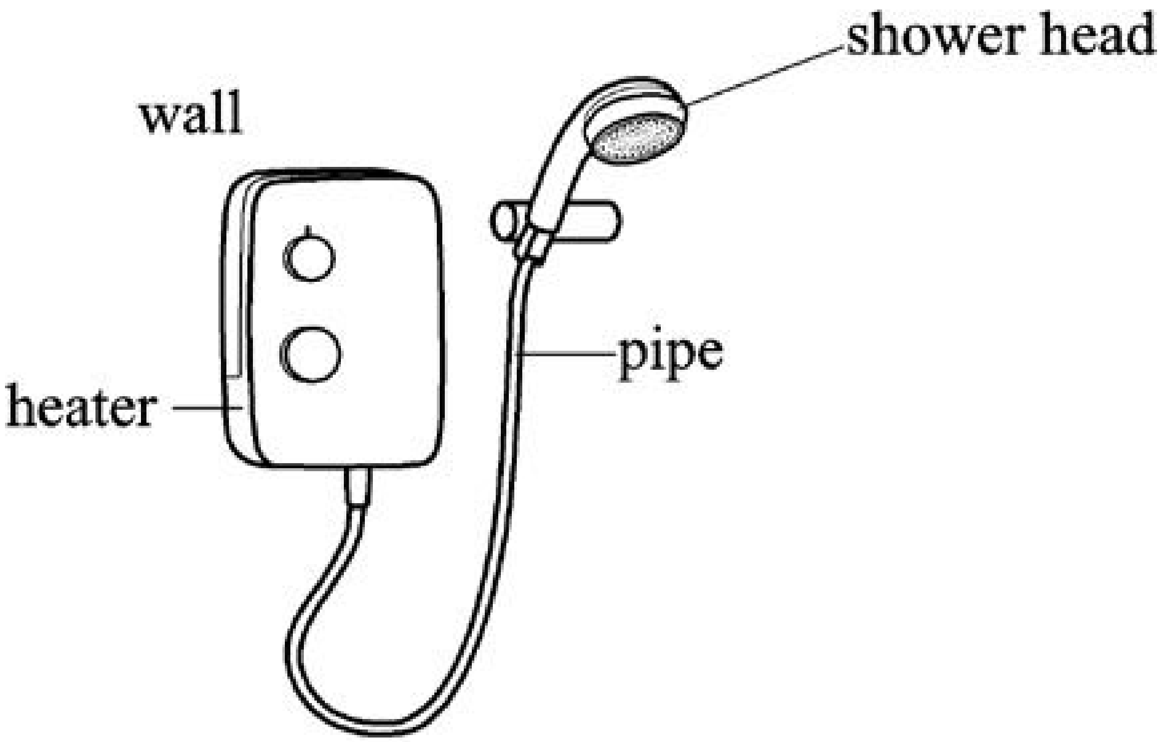


Fig.1.1

The water enters the heater at a temperature of 14 °C. At the maximum flow rate of 0.070 kg s^{-1}, the water leaves the shower head at a temperature of 30 °C.

Calculate the rate at which energy is transferred to the water. Give a suitable unit for your answer.

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

rate of energy transfer = _______________ unit _______ **[3]**

15 Uranium-235 is used in many fission reactors as fuel and fusion reactors are still at an experimental stage.

(i) State one major disadvantage of having fission reactors.

--- [1]

(ii) The fission of a uranium-235 nucleus releases about 200 MeV of energy, whereas the fusion of four hydrogen-1 nuclei releases about 28 MeV.

At first sight it would appear that fusion would produce less energy than fission. However the energy released in the fission of one kilogramme of uranium-235 is about eight times less than the energy released in the fusion of one kilogramme of hydrogen-1.

Explain this by considering the initial number of particles in one kilogramme of each.

--- [4]

16(a) The equation of state of an ideal gas is $pV = nRT$. Explain why the temperature must be measured in kelvin.

--- [2]

(b) A meteorological balloon rises through the atmosphere until it expands to a volume of $1.0 \times 10^6\ m^3$, where the pressure is 1.0×10^3 Pa. The temperature also falls from 17 °C to – 43 °C.

The pressure of the atmosphere at the Earth's surface = 1.0×10^5 Pa.

Show that the volume of the balloon at take off is about $1.3 \times 10^4\ m^3$.

[3]

(c) The balloon is filled with helium gas of molar mass 4.0×10^{-3} kg mol^{-1} at 17 °C at a pressure of 1.0×10^{5} Pa.

Calculate

(i) the number of moles of gas in the balloon

number of moles = ____________________ **[2]**

(ii) the mass of gas in the balloon.

mass = ____________________ kg **[1]**

(d) The internal energy of the helium gas is equal to the random kinetic energy of all of its molecules.

When the balloon is filled at ground level at a temperature of 17 °C, the internal energy is 1900 MJ.

Estimate the internal energy of the helium when the balloon has risen to a height where the temperature is –43 °C.

internal energy = ______________ MJ **[1]**

(e) The acceleration of the balloon and its instruments at the Earth's surface as it is released is 27 m s^{-2}.

The density of the air at the Earth's surface is 1.3 kg m^{-3}.

Calculate the total mass *M* of the helium-filled balloon and its load.

M = ______________ kg **[3]**

17(a) Fig. 6.1 shows a tube containing small pellets of lead. When the tube is inverted the pellets of lead fall freely through a vertical height equal to the length of the tube. The pellets are warm after the tube has been inverted many times.

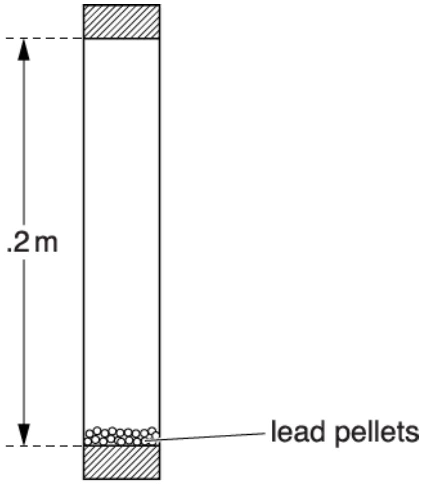


Fig. 6.1

The tube is used in an experiment to determine the specific heat capacity of lead. The following results are obtained.

total mass of lead pellets = 0.025 kg

number of inversions = 50

length of tube = 1.2 m

change in temperature of the lead = 4.5 °C

Use this information to calculate the specific heat capacity of the lead.

specific heat capacity ____________________________ J kg^{-1} K^{-1} **[4]**

(b) State **two** assumptions you have made in your calculation of the specific heat capacity.

---

[2]

(c) State and explain the change, if any, you would expect to see in the temperature rise if the mass of the lead pellets is doubled.

---

[2]

18(a) Explain how the *internal energy* of an ideal gas is related to its temperature.

In your answer, you should use appropriate technical terms spelled correctly.

____

____

____

____

____ **[2]**

(b) A weather balloon is designed to be inflated to a maximum volume of 1.4×10^4 m^3. To launch the balloon it is partially inflated with 80 kg of helium at a pressure of 1.0×10^5 Pa and a temperature of 21 °C.

molar mass of helium = 0.004 kg mol^{-1}

(i) Calculate the volume of the partially inflated balloon.

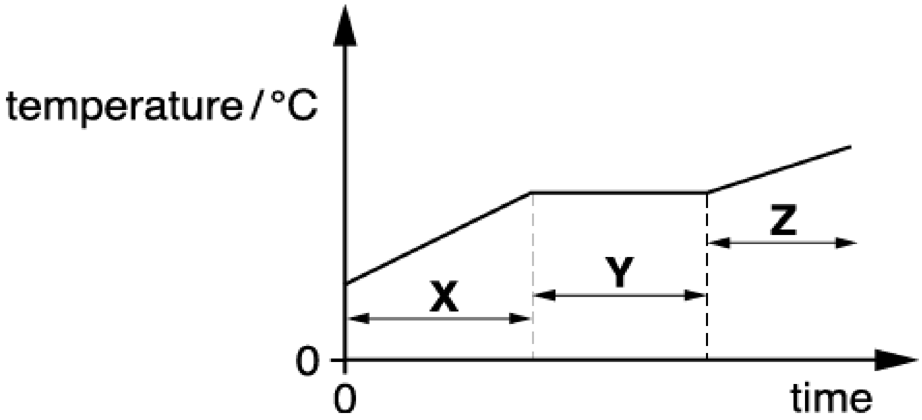
volume = ______________________________ m^3 **[3]**

(ii) To limit the maximum height that the balloon can reach, helium is allowed to leak out through a control valve. Determine the number of moles of helium that need to escape for the weather balloon to reach its maximum volume when the pressure is 1.2×10^3 Pa and the temperature is –40 °C.

number of moles = ____________________________ mol **[2]**

19 A metal is heated using a heater of constant output power.

The graph below shows the variation of the temperature of the metal with time.



The metal is a solid in region X, a mixture of solid and liquid in region Y and a liquid in region Z.

Which row shows the best description of the energy of the atoms of the metal?

	Internal energy of the atoms	Potential energy of the atoms	Kinetic energy of the atoms
A	constant throughout	constant throughout	constant throughout
B	increases with time in X and Z	increases with time in X and Z	constant in only Y
C	increases with time in X, Y and Z	increases with time in X and Z	increases with time in only Y
D	increases with time in X, Y and Z	increases with time in only Y	increases with time in X and Z

Your answer

[1]

20 A gas syringe contains 2.0 moles of an ideal gas of volume of 0.040 m^3.
An additional amount of 0.5 moles of the same gas is added to the syringe. The temperature and pressure of the gas remain the same.

What is the final volume of gas in the syringe?

A 0.010 m^3
B 0.032 m^3
C 0.050 m^3
D 0.090 m^3

Your answer [ ]

[1]

21 A satellite is in a circular orbit around the Earth. The vertical **height** of the satellite above the surface of the Earth is 3200 km. The radius of the Earth is 6400 km.

What is the ratio

$$\frac{\text{weight of satellite in orbit}}{\text{weight of satellite on the Earth's surface}}?$$

A 0.25
B 0.44
C 0.50
D 0.67

Your answer [ ]

[1]

22(a) Define *specific heat capacity* of a substance.

--- [1]

(b) A group of students conduct an experiment using water to heat glycerol in a boiling tube. The apparatus they use is shown in Fig. 20.1.

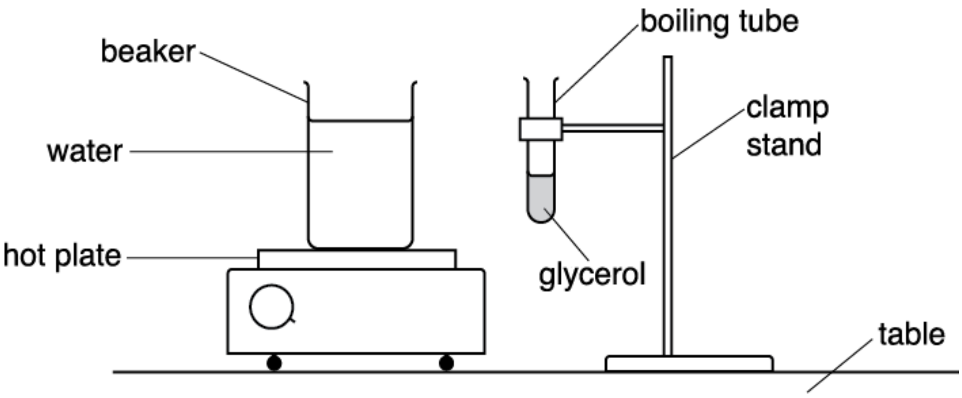


Fig. 20.1

The table below shows the mass m and the specific heat capacity c for water and glycerol used in the experiment.

	m / g	c / J kg^{-1} K^{-1}
Water	150	4200
Glycerol	20	2400

(i) The water is initially heated from 20 °C to 75 °C on a hot plate.
Calculate the energy supplied to the water.

energy = ______________________________ J **[1]**

(ii) The beaker of hot water at 75 °C is removed from the hot plate.
The boiling tube, which contains the glycerol at 20 °C, is now placed into the hot water.
Both liquids reach a common temperature θ.

Calculate the temperature θ.

θ = ______________________________ °C **[3]**

(iii) Explain why the actual temperature θ is different from your value calculated in **(ii)**.

____

____ **[1]**

(c) In a specialist laboratory, energy is supplied at a constant power to solid glycerol initially at a temperature of −100 °C. The glycerol is then heated from this temperature until it boils.
The specific heat capacity of solid glycerol is less than the specific heat capacity of liquid glycerol. Glycerol melts at a temperature of about 20 °C and starts to boil at a temperature of about 290 °C.

Sketch a graph on Fig. 20.2 to show the variation of the temperature of glycerol with time.
Assume that there is no heat transfer to the surroundings.

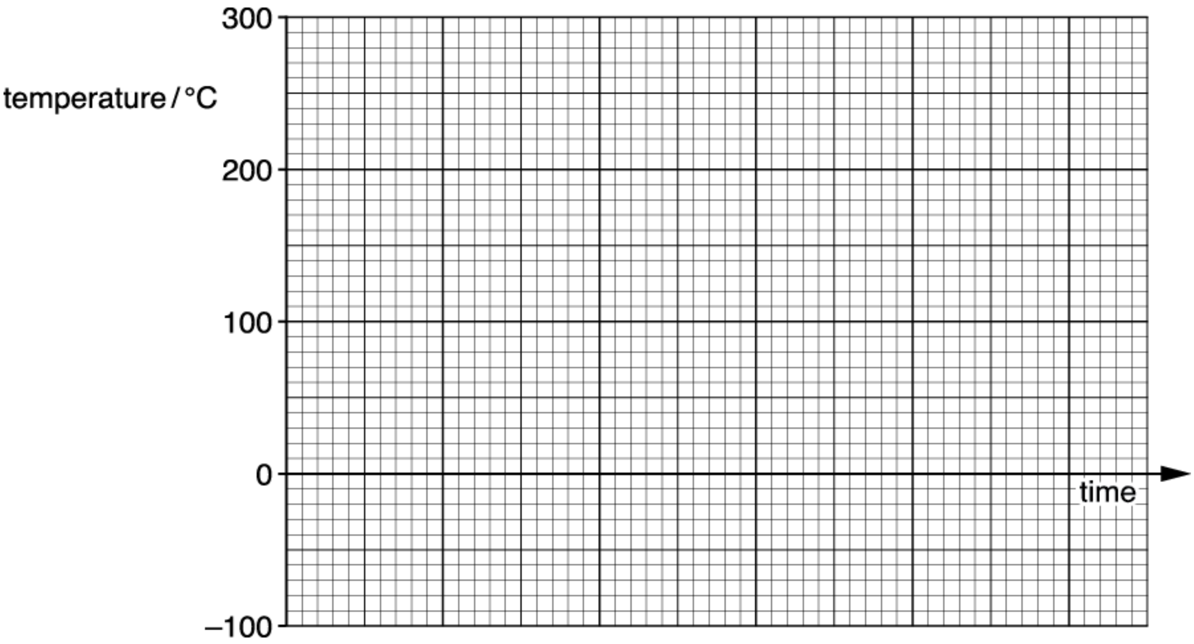


Fig. 20.2

[3]

23 This question is about helium in the atmosphere of the Earth.

Experiment shows that most of the Earth's atmosphere is contained within a very thin shell around the surface of the Earth. Less than 0.0001% of this is helium.

The height of the atmosphere is negligible compared with the radius *R* of the Earth.

(i) Show that the minimum speed v_E required for an atom or molecule to escape from the top of the Earth's atmosphere is given by the expression

$$v_E = \sqrt{2gR}\,.$$

[3]

(ii) The radius *R* of the Earth is 6.4×10^6 m. Calculate this escape speed v_E.

v_E = ______________________________ m s^{-1} **[1]**

(iii) Calculate the temperature *T* in kelvin required at the top of the Earth's atmosphere for the root mean square speed $c_{r.m.s.}$ of the helium atoms there to equal this escape speed.

Molar mass of helium = 0.004 kg mol^{-1}

T = ______________________________ K **[3]**

(iv) Fig. 1 shows the distribution of the speeds of the atoms of an ideal gas.

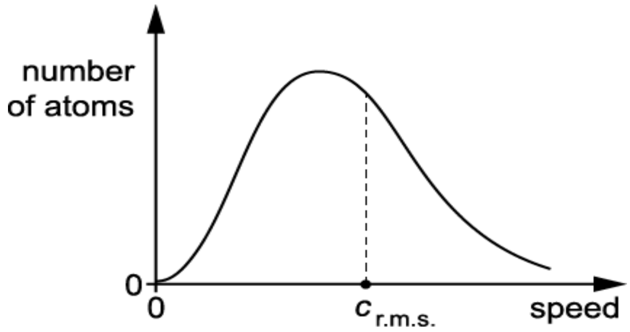


Fig. 1

Use your knowledge of the kinetic theory of gases to describe the shape of this distribution and explain why some helium is able escape from the Earth.

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____ **[4]**

(v) Over a very long period of time all of the helium should have escaped from the Earth. Suggest why there is still a small amount of helium, about 0.0001%, in the Earth's atmosphere.

____

____

____ **[2]**

24(a) Lasers are often used to form precision-welded joints in titanium. To form one such joint it is first necessary to increase the temperature of the titanium to its melting point. Fig. 5.1 shows the joint and the volume of titanium to be heated.

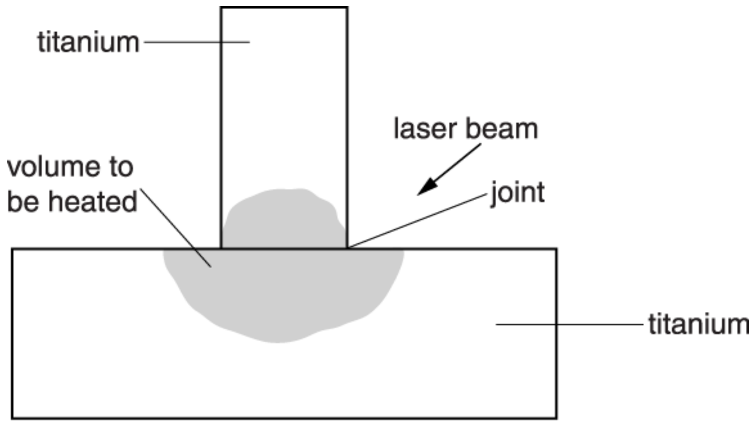


Fig. 5.1

The photon beam from the laser is focused onto the shaded volume of the joint and is converted into thermal energy in the titanium.

The wavelength of the photons is 1.1×10^{-6} m.

Show that the energy of a photon in the beam is 1.8×10^{-19} J.

[1]

(b) Photons are emitted from the laser at a constant rate of $6.3 \times 10^{19}\ s^{-1}$.

Estimate the time taken to raise the temperature of the shaded volume of titanium shown in Fig. 5.1 to melting point. Use the data below for your calculations.

initial temperature = 20 °C
melting point of titanium = 1700 °C
density of titanium = $4.5 \times 10^{3}\ kg\ m^{-3}$
specific heat capacity of titanium = $520\ J\ kg^{-1}\ K^{-1}$
shaded volume of titanium being heated = $8.1 \times 10^{-12}\ m^{3}$.

time = ______________________________ s **[3]**

(c) In practice it takes a longer time to reach the melting point.
State and explain **two** factors that will increase the time taken.

____

____

____

____ **[2]**

(d) To complete the weld more photons must be focused onto the joint. During this final stage the temperature remains constant. Explain why this is to be expected.

____

____

____ **[1]**

25 A container has an ideal gas. The mean square speed of the gas molecules in the container is 3.0×10^5 m^2 s^{-2}.

Over a period of time, a third of the gas molecules escape from the container. The pressure and volume of the gas in the container remain the same.

What is the mean square speed of the molecules left in the container?

A 1.0×10^5 m^2 s^{-2}

B 2.0×10^5 m^2 s^{-2}

C 4.5×10^5 m^2 s^{-2}

D 9.0×10^5 m^2 s^{-2}

Your answer ☐ **[1]**

26(a) A group of students are conducting an experiment in the laboratory to determine the value of absolute zero by heating a fixed mass of gas. The volume of the gas is kept constant.

Fig. 17.1 shows the arrangement used by the students.

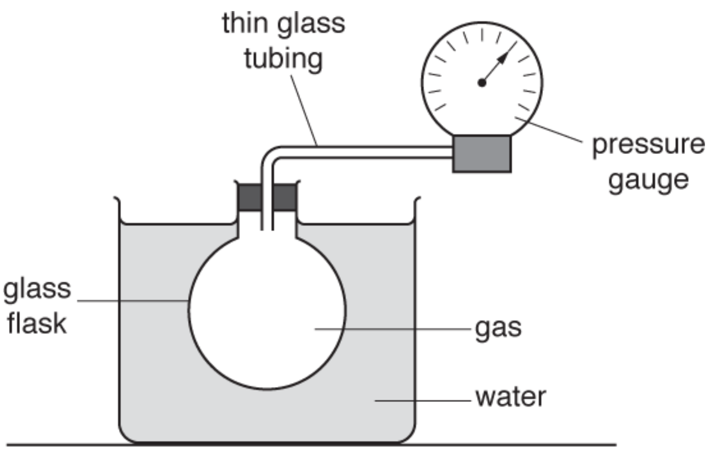


Fig. 17.1

The gas is heated using a water bath. The temperature θ of the water is increased from 5 °C to 70 °C.
The temperature of the water bath is assumed to be the same as the temperature of the gas. The pressure p of the gas is measured using a pressure gauge.

The results from the students are shown in a table.

θ / °C	p / kPa
5 ± 1	224 ± 3
13 ± 1	231 ± 3
22 ± 1	238 ± 3
35 ± 1	248 ± 3
44 ± 1	
53 ± 1	262 ± 3
62 ± 1	269 ± 3
70 ± 1	276 ± 3

Describe and explain how the students may have made accurate measurements of the temperature θ.

--- [2]

(b) Fig. 17.2 shows the pressure gauge. Measurements of p can be made using the kPa scale or the psi (pounds per square inch) scale. The students used the psi scale to measure pressure and then converted the reading to pressure in kPa.

Fig. 17.2

(i) Suggest why it was sensible to use the psi scale to measure p.

--- [1]

(ii) The students made a reading of p of 37.0 ± 0.5 psi when θ was 44 ± 1°C.
Convert this value of p from psi to kPa. Complete the table for the missing value of p. Include the absolute uncertainty in p.

1 pound of force = 4.448 N

1 inch = 0.0254 m

[2]

(c) Fig. 17.3 shows the graph of p against θ.

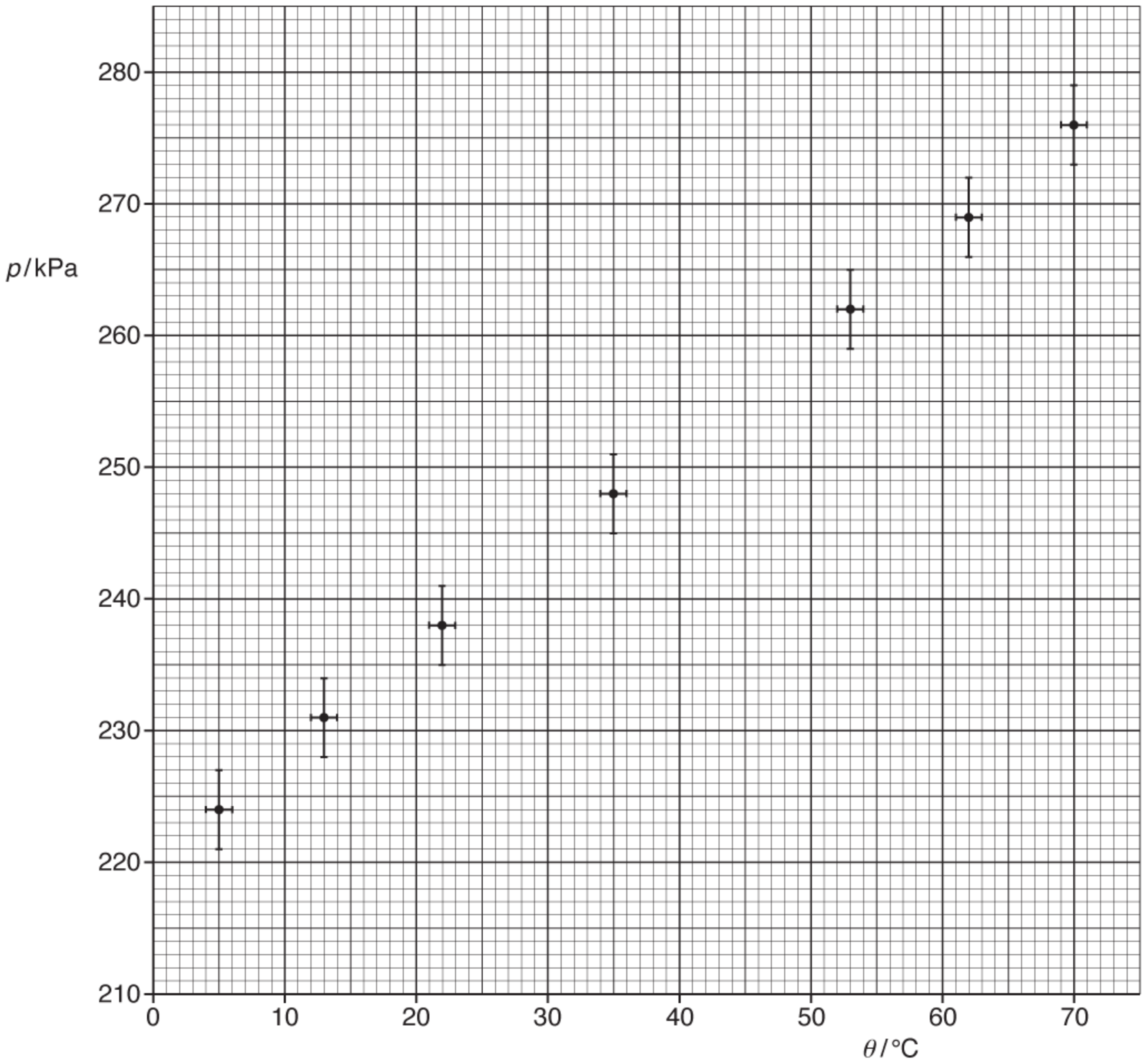


Fig. 17.3

(i) Plot the missing data point and the error bars on Fig. 17.3.

[1]

(ii) Explain what is meant by *absolute zero*. Describe how Fig. 17.3 can be used to determine the value of absolute zero.

Determine the value of absolute zero. You may assume that the gas behaves as an ideal gas.

[6]

(d) Describe, without doing any calculations, how you could use Fig. 17.3 to determine the actual uncertainty in the value of absolute zero in **(c)(ii)**.

[2]

(e) The experiment is repeated as the water bath quickly cools from 70 °C to 5 °C. Absolute zero was found to be –390°C.

Compare this value with your value from **(c)(ii)** and explain why the values may differ. Describe an experimental approach that could be taken to avoid systematic error in the determination of absolute zero.

[4]

27 A plastic kettle is filled with 0.60 kg of water at a temperature of 20°C.
A 2.2 kW electric heater is used to heat the water for a time of 4.0 minutes.

The specific heat capacity of water is 4200 J kg^{-1} K^{-1} and the specific latent heat of vaporisation of water is 2.3×10^6 J kg^{-1}. The boiling point of water is 100°C.

Calculate the mass of water **remaining** in the kettle after 4.0 minutes.
Assume that all the thermal energy from the heater is transferred to the water.

mass of water remaining = ____________________ kg **[4]**

28(a)

Define the *internal energy* of a substance.

--- **[1]**

(b) A block of paraffin wax is melting at a constant temperature of 52 °C. Use the behaviour of paraffin molecules to describe and explain the changes to the internal energy of the molecules of the paraffin wax as it melts.

[4]

29

The table below shows some data for Mercury and Pluto.

	Mass / kg	Radius / m	Mean distance from Sun / m
Mercury	3.30×10^{23}	2.44×10^{6}	57.9×10^{9}
Pluto	0.131×10^{23}	1.19×10^{6}	5910×10^{9}

(i) Show that the escape velocity *v* of a gas molecule on the surface of Pluto is given by the equation

$$v = \sqrt{\frac{2GM}{r}}$$

where *M* is the mass of Pluto and *r* is its radius.

[2]

(i) Calculate the escape velocity *v* of gas molecules on the surface of Pluto.

v = ____________________ m s^{-1} **[1]**

(ii) Explain why Mercury has no atmosphere whilst Pluto still has a thin atmosphere. Use data from the table to support your explanation.

____

____

[3]

A loudspeaker mounted on a bench is emitting sound of frequency 1.7 kHz to a microphone. Fig. 5.1 shows an illustration of the bulk movement of the air at one instant of time.

Fig. 5.1

The maximum displacement of the air particles from their mean positions is 2.0×10^{-6} m.

The speed of sound in air at 17 °C is 340 m s^{-1}.

(i) On Fig. 5.2, sketch the sinusoidal variation of the displacement of the air with distance between **C** and **R**.

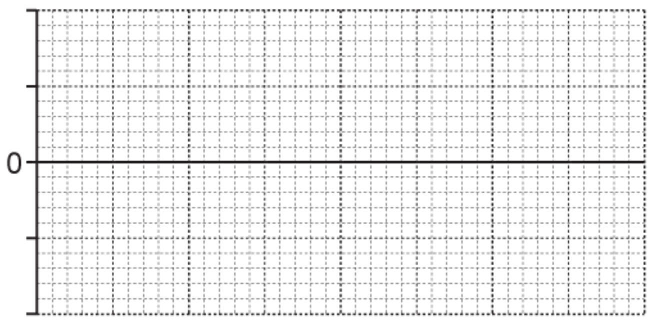


Fig. 5.2

1 Label the axes and include sensible scales.
2 On Fig. 5.2, mark one point where air particles are moving at maximum speed. Label it **X**.
3 On Fig. 5.2, mark one point where air particles are moving at maximum speed but travelling in the opposite direction to the air particles in **2**. Label it **Y**.

[4]

(ii) Calculate

1 the maximum speed v_{max} of the oscillating particles in the sound wave

v_{max} = ____________________ m s^{-1} **[2]**

2 the root mean square speed *c* of the air molecules in the room.
The molar mass of air is 2.9×10^{-2} kg mol^{-1}.

c = ____________________ m s^{-1} **[2]**

31 A metal block of mass 0.28 kg has an initial temperature of 82 °C. It is dropped into cold water. The temperature of the block after 1.2 minutes is 20 °C.
The specific heat capacity of the metal is 130 J kg^{-1} K^{-1}.

What is the average thermal power transferred away from the metal block?

A 31 W
B 41 W
C 1900 W
D 2700 W

Your answer [ ] **[1]**

32 The latent heat of vaporisation of a liquid is 2300 kJ kg^{-1} and it has a molar mass of 0.018 kg mol^{-1}.

What is the energy required to change 30 moles of the liquid to gas?

A 4.1×10^4 J
B 1.2×10^6 J
C 6.9×10^7 J
D 3.8×10^9 J

Your answer [1]

33 The volume of one mole of an ideal gas is *V*. The gas exerts pressure *p* and has thermodynamic temperature *T*.

Which of the following has the units J mol^{-1} K^{-1}?

A pV
B $\frac{p}{T}$
C $\frac{V}{T}$
D $\frac{pV}{T}$

Your answer [1]

34 There is a lot of helium in the Universe. This was also true of the Earth when it was formed billions of years ago. However, only small traces of helium are now found in the atmosphere of the Earth.

Use the kinetic theory of gases to explain why only small amounts of helium are found in the Earth's atmosphere. Use the information below to do suitable calculations to support your answer.

- typical atmospheric temperature = 10 °C
- mass of helium atom = 6.64×10^{-27} kg
- escape velocity from the Earth = 11 km s^{-1}

[6]

35(a) A toy rocket is made from a 1.5 litre plastic bottle with fins attached for stability.

The bottle initially contains 0.30 litres of water, leaving 1.2 litres of trapped air at a temperature of 17 °C.
A pump is used to increase the pressure of the air within the plastic bottle to 2.4×10^5 Pa at the start of lift-off.

Fig. 1.1 shows the rocket at the start of lift-off.

1 litre = 10^{-3} m^3

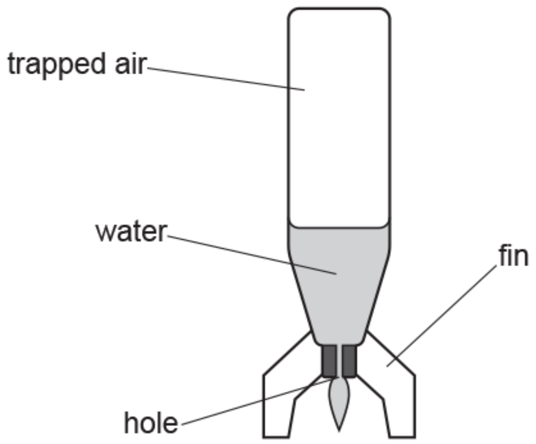


Fig. 2.1

Calculate, in moles, the amount of trapped air in the bottle at the start of lift-off.

amount of air = ... mol **[2]**

(b) The trapped air pushes the water downwards out of the hole, causing the rocket to rise.
The temperature of this air remains constant.

Calculate the final pressure of the trapped air just before all the water has been released.

final pressure = ...Pa **[3]**

(c) Here is some data on the toy rocket.

mass of empty bottle and fins = 0.050 kg
area of cross-section of hole = 1.1×10^{-4} m^2
initial pressure of trapped air = 2.4×10^5 Pa
atmospheric pressure = 1.0×10^5 Pa
density of water = 1.0×10^3 kg m^{-3}

(i) Use the data above to show that the **upwards** force on the rocket at the start of lift-off is about 15 N.

[2]

(ii) Hence calculate the initial vertical acceleration of the rocket.

initial acceleration = ... m s^{-2} **[3]**

36 A solid molecular substance is supplied with energy and it starts to melt.

Which of the following pairs of quantities remains the same as the substance melts?

A Kinetic energy of molecules and internal energy of molecules.

B Potential energy of molecules and internal energy of molecules.

C Kinetic energy of molecules and temperature of substance.

D Potential energy of molecules and temperature of substance.

Your answer [ ] **[1]**

37(a) A substance can exist as a crystalline solid, a liquid or a gas.

A solid sample of the substance is placed in a sealed container and heated at a constant rate until it changes into a gas.

Fig. 21 shows the variation with time *t* of the temperature *θ* for the substance.

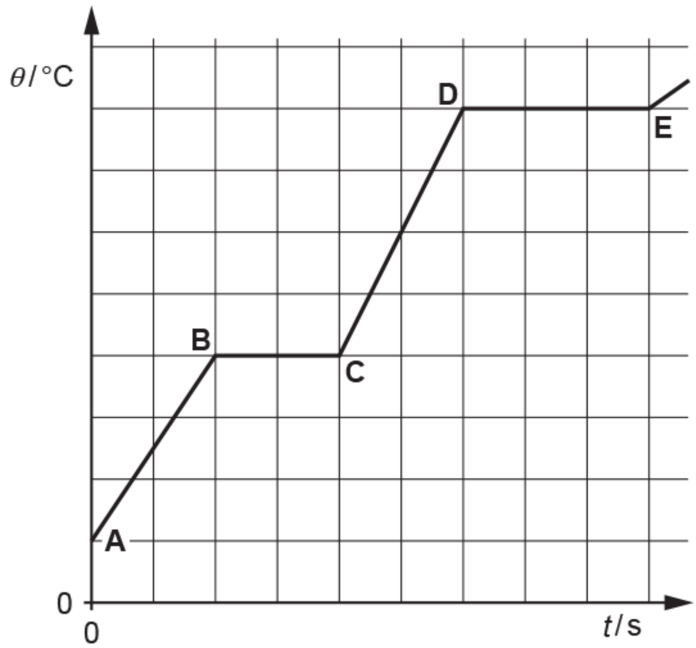


Fig. 21

Use the kinetic theory of matter to describe the solid phase (section **AB**) and the liquid phase (section **CD**) in terms of the motion and arrangement of the molecules of the substance.

Section **AB**: ____

____

____

____

____

____

Section **CD**: ____

[4]

(b) Use Fig. 21 to explain how the specific heat capacity of the liquid compares with the specific heat capacity of the solid.

[2]

(c) State what is meant by the **internal energy** of the substance.

[1]

(d) Beyond the point **E** in Fig. 21, the substance behaves as an ideal gas.

(i) The mass of a gas molecule is 4.8×10^{-26} kg.
Calculate the root mean square speed of the gas molecules at a temperature of 250 °C.

root mean square speed = ... m s^{-1} **[3]**

(ii) Calculate the internal energy of 1.3 moles of the gas at 250 °C.

internal energy = ... J **[3]**

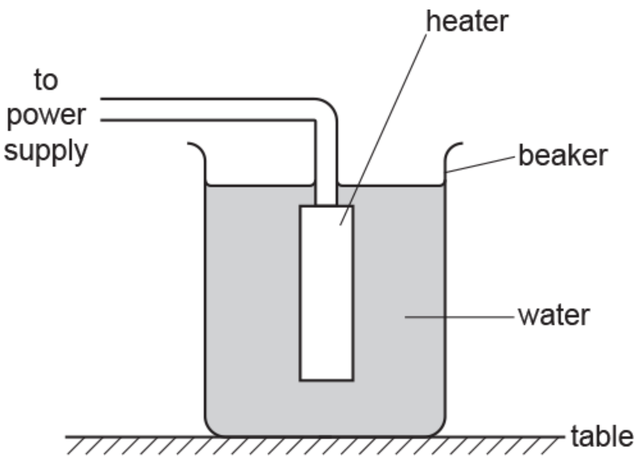
38 The kinetic theory of matter is a model used to describe the behaviour of particles (atoms or molecules) in an ideal gas. There are a number of assumptions made in the kinetic model for an ideal gas.

Which one of the following assumptions is **not** correct?

A The collisions of particles with each other and the container walls are perfectly inelastic.
B The electrostatic forces between particles are negligible except during collisions.
C The particles occupy negligible volume compared to the volume of the gas.
D There are a large number of particles in random motion.

Your answer ☐ **[1]**

39(a) A heater is used to heat water in a beaker.



(i) Before switching on, the metal heater and the water are both at room temperature.

Describe the motion of the atoms of the metal heater and of the water molecules.

____

____

____

____

____

____ **[3]**

(ii) The heater is now switched on.

The power of the heater is 200 W.

The mass of the water in the beaker is 500 g.

It takes 10.0 minutes to increase the temperature of the water in the beaker from 20 °C to 60 °C.

Calculate the energy transferred from the water to the **beaker and the surroundings** .

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

energy transferred = ... J **[3]**

(b) * A student is carrying out an experiment to determine the specific latent heat of fusion L_f of ice. The student has two sets of apparatus next to each other on the laboratory bench, as shown in **Fig. 17.1** and **Fig. 17.2**.

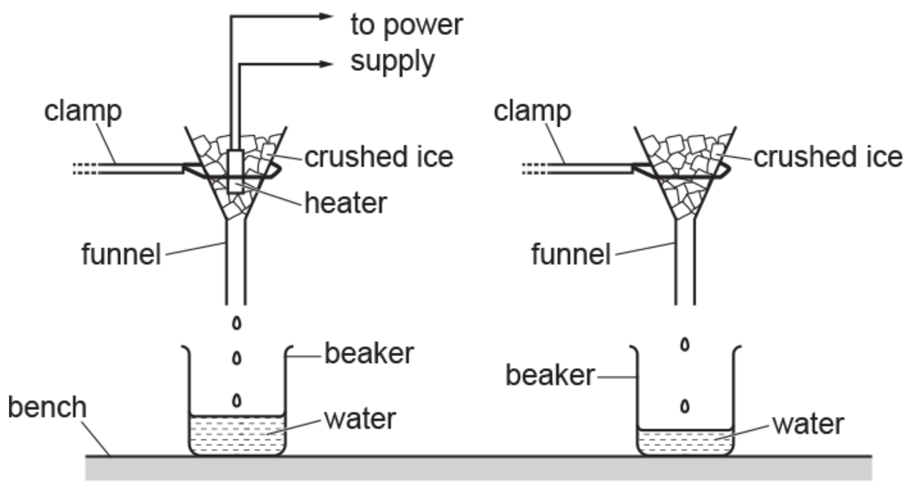


Fig. 17.1 **Fig. 17.2**

Both funnels are identical and have the same mass of crushed ice at 0 °C.

The current in the heater is 5.0A and the potential difference across it is 12 V.

Fig. 17.3 shows the variation of mass of water *m* collected in each beaker with time *t*.

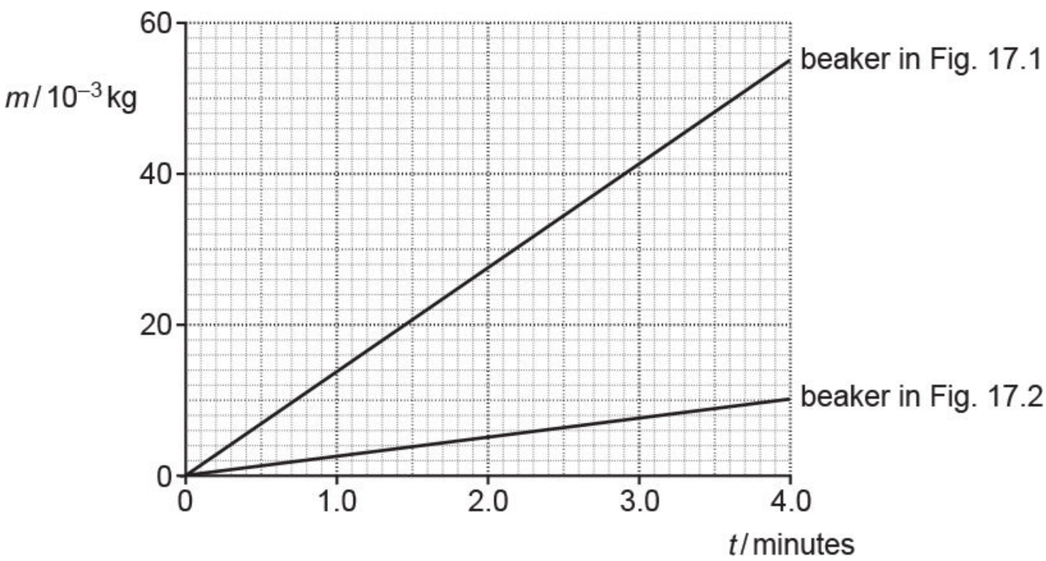
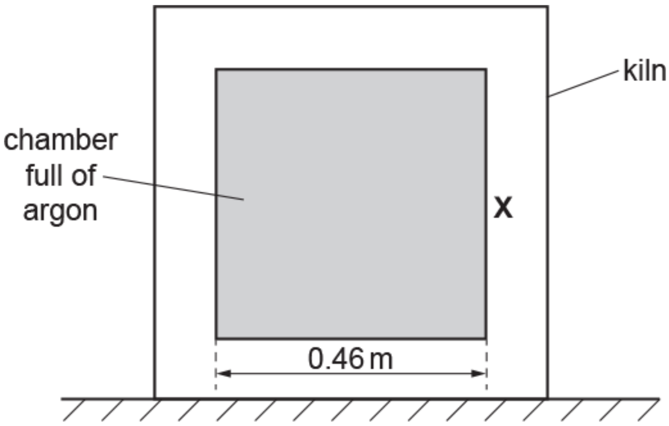


Fig. 17.3

Describe and explain the shape of the two graphs in **Fig. 17.3** and use them to determine the specific latent heat of fusion L_f of ice.

[6]

40(a) A kiln used to harden ceramics is shown below.



The internal chamber is a cube. Each side of this cube has length 0.46 m.
The chamber is sealed and full of argon. Argon behaves as an ideal gas.

The kiln is initially at 20 °C.
The argon in the kiln has an initial pressure of 100 kPa.

(i) Calculate the amount of argon n in the chamber in moles.

n = ... mol **[2]**

(ii) The temperature of the kiln is increased from 20 °C to 1300 °C.

Calculate the pressure in kPa at 1300 °C.

pressure = ... kPa **[2]**

(b) The temperature of the kiln is 1300 °C.
A single atom of argon is travelling horizontally towards the vertical side **X** of the chamber.
The initial speed of this atom is 990 m s^{-1}. After collision, it rebounds at the same speed.

(i) Calculate the change in momentum Δp of this atom.

- mass of argon atom = 6.6×10^{-26} kg

Δp = ... kg m s^{-1} **[2]**

(ii) Assume that this atom does not collide with any other argon atoms inside the chamber. Instead, it travels horizontally, making repeated collisions with the opposite vertical walls of the chamber.

1 Show that the atom makes about 1000 collisions with side **X** in a time interval of 1.0 s.

[1]

2 Calculate the average force *F* on side **X** made by the atom.

F = ... N **[2]**

(iii) Without calculation, explain how your answer to **(ii)2** could be used to estimate the total pressure exerted by the atoms of the argon gas in the kiln.

-- **[2]**

41(a) The International Space Station (ISS) orbits the Earth at a height of 4.1×10^5 m **above** the Earth's surface.

The radius of the Earth is 6.37×10^6 m. The gravitational field strength g_0 at the Earth's surface is 9.81 N kg^{-1}.

Both the ISS and the astronauts inside it are in free fall.

Explain why this makes the astronauts feel **weightless**.

---

[1]

(b)

(i) Calculate the value of the gravitational field strength g at the height of the ISS above the Earth.

g = ... N kg^{-1} **[3]**

(ii) The speed of the ISS in its orbit is 7.7 km s^{-1}. Show that the period of the ISS in its orbit is about 90 minutes.

[2]

(c) Use the information in **(b)(ii)** and the data below to show that the root mean square (r.m.s.) speed of the air molecules inside the ISS is approximately 15 times smaller than the orbital speed of the ISS.

- molar mass of air = 2.9×10^{-2} kg mol^{-1}
- temperature of air inside the ISS = 20 °C

[3]

(d) The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

Use the data below and your answer to **(b)(ii)** to calculate the **average** power delivered to the batteries.

- The total area of the cells facing the solar radiation is 2500 m^2.
- 7% of the energy of the sunlight incident on the cells is stored in the batteries.
- The intensity of solar radiation at the orbit of the ISS is 1.4 kW m^{-2} outside of the Earth's shadow and zero inside it.
- The ISS passes through the Earth's shadow for 35 minutes during each orbit.

average power = ... W **[4]**

42 This question is about the Sun and its radiation.

* A student attends a lecture about the Sun and makes the following notes.

1. The Sun loses more than 4×10^9 kg of its mass every second to maintain its luminosity.
2. Treating hydrogen nuclei (protons) as an ideal gas, a temperature of 10^{10} K provides a kinetic energy of about 1 MeV, which is necessary for fusion.
3. However, the Sun's core temperature is only 10^7 K, so the chance of protons fusing on collision is very small. This explains why the Sun has such a long lifetime.

Explain the principles of physics which are involved in each of the three points.
You should include relevant formulae, but no numbers or calculations are required.

[6]

END OF QUESTION PAPER

Question			Answer/Indicative content	Marks	Guidance
1			C	1	
			Total	1	
2			A	1	
			Total	1	
3			B	1	
			Total	1	
4	a		number of moles = 0.327 / 0.018 = 18.17 number of molecules = 18.17 × N_A number of molecules = 1.1 × 10^{25}	C1 A1	
	b		energy input = $mc\Delta\theta$ = 0.327 × 4200 × 80 = 110 kJ energy input = power × time time = 220 (s)	C1 M1 C1 A0	Allow 0.3 kg in the calculation
	c		Thermal losses to kettle and surroundings Lagging the kettle Cover to prevent evaporation	B1 B1 B1	
			Total	8	
5	a		Smoke particles show random / haphazard motion (wtte) This is because of collisions with air molecules / particles.	B1 B1	Accept a correctly labelled diagram for this B1 mark.
	b		Any **three** from: • Forces between particles are negligible except during collisions • Collisions are perfectly elastic • Time of a collision is negligible compared to time between collision • Particles / atoms / molecules occupy negligible volume compared to volume of gas • Large number of molecules in random motion.	B1 × 3	
	c	i	T = 293 K	M1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	3/2 kT = ½ mv^2	C1	
		i	3/2 × 1.38 × 10^{-23} × 293 = ½ × 4.7 × 10^{-26} × v^2	M1	
		i	v = 510 (m s^{-1})	A0	Note answer is 509.8 m s^{-1} to 4 s.f.
		ii	1. Total vertical momentum after = 0 Total vertical momentum before = 0 (momentum is conserved)	B1 B1	
		ii	2. 4.7 × 10^{-26} × v × sin 88° = 1.4 × 10^{-24} × 23 × sin 45°	C1	
		ii	v = 480 (m s^{-1})	A1	**Allow** other correct methods.
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
6	a		Ensure largest possible proportion of flask is immersed. Make volume of tubing small compared to volume of flask. Remove heat source and stir water to ensure water at uniform temperature throughout. Allow time for heat energy to conduct through glass to air before reading temperature.	B1 × 4	
	b	i	Pressure is caused by collisions of particles with sides.	B1	
		i	Velocity of particles (and volume of gas) are not zero at 0 °C.	B1	
		ii	**1:** Gradient of graph $0.75 \times 10^2 / 100 = 0.75$		
		ii	Number of moles of gas = gradient / R = 0.75 / 8.31 = 0.09	C1	Alternative method Internal energy = 3/2 × p × V
		ii		A1	
		ii	Mass of gas = $0.09 \times 6.02 \times 10^{23} \times 4.7 \times 10^{-27} = 2.5 \times 10^{-4}$ (kg)		At θ = 100°C pV = 2.73×10^2
		ii	**2:** Internal energy = 3/2 × NkT		Internal energy = $1.5 \times 2.73 \times 10^2 = 410$ (J)
		ii	= $1.5 \times 0.09 \times 6.02 \times 10^{23} \times 1.38 \times 10^{-23} \times (100 + 273)$	C1	
		ii	= 410 (J)	A1	
			Total	10	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
7	a		Idea of extrapolating graph back (to negative temperatures) Volume is zero at absolute zero / negative volumes are impossible	B1 B1	Can be shown on diagram Allow 'negligible volume' rather than zero and use of -273 °C / 0 K **Examiner's Comments** Although the term 'extrapolate' was not commonly seen, most candidates understood the need to extend the line back until it cut the temperature axis in order to justify their comments about negative volumes and the temperature scale. Many referred to 'zero' or 'minimal volume' and this was credited by Examiners. A significant number of candidates talked about the kinetic energy and velocity of molecules in their answers and only loosely related this to the question. This was most unfortunate given that the graph given involved volume rather than either of these terms.
	b	i	(Internal energy of a system) is the sum of the random (distribution of) kinetic and potential energies of (all) **atoms / molecules** (in the system)	B1	**Allow:** particles **Examiner's Comments** This standard definition was poorly answered by many candidates. Candidates did not seem to be aware that a precise definition was required. Many candidates lost the mark as a result of omitting to specify that the energies were associated with the **molecules** of the gas and that the distributions were **random**, both of which are important features of internal energy. Since the question did not specify that the gas was ideal it was appropriate to include potential energy even though it is small for gases under 'normal' conditions.
		ii	Any **two** from Comparison of kinetic energies in gas and liquid phases linked to temperature	B1	

Question			Answer/Indicative content	Marks	Guidance
		ii	Potential energy of gas phase is greater than PE of liquid phase / energy must be supplied to change liquid into gas phase.	B1	**Allow:** potential energy of gas phase is ('close' to) zero **Examiner's Comments** Although this was a topic that was well understood in general it was not common to see both marks scored. In most cases this was because only the most able candidates linked the kinetic energy of the molecules to temperature. Some candidates didn't distinguish clearly enough in their answers which phase had the higher internal energy by ambiguous use of 'it'.
	c	i	$p = \frac{nRT}{V} = \frac{45 \times 8.31 \times 293}{1.2 \times 10^{-2}}$	C1	**No credit** If temperature is not converted to kelvin
		i	$p = 9.1 \times 10^6$ (Pa)	A1	**Examiner's Comments** This calculation was very well answered, with only a small minority using temperature on the celsius scale. As in previous years the penalty of this serious error in physics was fairly high in this question.
		ii	$n_{He} = \frac{5.0 \times 10^7 \times 2.0 \times 10^{-3}}{8.31 \times 293} = 41$	C1	**Allow:** ECF if temperature is used in °C only if penalised in (i) Otherwise max mark allowed is 1 out of 3 for n = 602 mol
		ii	$p_{trimix} = \frac{[45 + 41] \times 8.31 \times 293}{[1.2 \times 10^{-2} + 2.0 \times 10^{-3}]}$	C1	**Allow:** use of partial pressures

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$p_{trimix} = 1.5 \times 10^7$ (Pa)	A1	**Examiner's Comments** Weaker students struggled with this question frequently managing only to score the mark for the number of moles of helium added. The most common error was to assume that the volume remained the same. Very few candidates attempted to solve the problem by using partial pressures and, of those who did, most only scored one mark, usually for determining the partial pressure of one of the gases. In some case it appeared that, although the calculation gave a correct partial pressure and consequently received a mark, the candidates were not actually aware that this could lead to the required total pressure value. A small minority attempted to use $p_1V_1/T_1 = p_2V_2/T_2$ apparently unaware that this formula is only applicable to situations in which the mass or number of molecules of gas is constant. In order to prevent an excessive penalty for the use of celsius temperatures in gas calculations on this paper Examiners ignored the use here, if it had been previously penalised.
		iii iii	Internal / kinetic energy of molecules decreases (as temperature falls) Hence pressure would decrease	M1 A0	**Allow:** $p \propto T$ if (n and) V constant **Examiner's Comments** This was another case where it was clear that the majority of candidates knew the answer but almost half failed to score the mark because they did not make clear that volume must remain constant for the pressure to be proportional to the absolute temperature.
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
8		i	$F = \dfrac{1.6\times10^{-19}\times1.6\times10^{-19}}{4\pi\varepsilon_0\times(10^{-14})^2}$	C1	**Not** $Q = q = 1$
		i	force = 2.3 (N)	A1	**Examiner's Comments** Generally, candidates answered the question well and got the correct answer of 2.3 N. The equation for Coulomb's law was familiar to most candidates and the substitution of numbers was clear with fewer calculator errors. A small number of candidates used charges of 2e and 3e and consequently scored no marks.
		ii	$E = 7.0\times10^4 \times 1.6\times10^{-19}$ (= 1.12×10^{-14} J)	C1	
		ii	($E = \frac{3}{2}kT$); $7.0\times10^4\times1.6\times10^{-19} = \frac{3}{2}\times1.38\times10^{-23}\times T$	C1	**Allow** any subject. Also, allow $E \approx kT$ since it is an estimate.
		ii	temperature = 5.4×10^8 (K)	A1	**Allow** 1 sf answer. **Examiner's Comments** The majority of the candidates scored three marks for this synoptic question requiring knowledge of electronvolts and mean kinetic energy $\frac{3}{2}kT$. The answers were, once again, well-structured and logically presented. A small number of candidates either used 70000 or 18 MeV as the mean kinetic energy; no marks were awarded for such elementary errors.
		iii	Some nuclei will be travelling faster / have greater (kinetic) energy (to overcome electrostatic repulsion and hence cause fusion).	B1	**Allow** the pressures are high (enough to cause fusion). **Not** 'nuclei get close enough'. **Examiner's Comments** This was a good discriminator, with top-end candidates giving perfect answers. Some even mentioned the Maxwell-Boltzmann distribution and how some of the nuclei would have kinetic energies greater than the mean kinetic energy. Descriptions were often far more complex than warranted by this one mark question. Examiners also allowed *'high pressure'* as a plausible answer.

Question			Answer/Indicative content	Marks	Guidance
		iv	($\Delta E = \Delta mc^2$); $18 \times 10^6 \times 1.6 \times 10^{-19} = \Delta m \times (3.0 \times 10^8)^2$	C1	**Allow** any subject
		iv	change in mass = 3.2×10^{-29} (kg)	A1	**Allow** a maximum of 1 mark for 18MeV ± 70 keV. **Examiner's Comments** This was another high-scoring question. Most candidates used the Einstein massenergy equation and the energy of 18 MeV converted to joules to get the correct answer. Examiners gave no marks if 70 keV was used as the energy. Once again, candidates demonstrated good analytical skills.
		v	Helium (nucleus) has greater charge / more protons.	B1	
		v	The (electrostatic) repulsive force (between the deuterium and helium nuclei) is greater (hence smaller chance of fusion).	B1	Do **not** award this mark if 'helium nuclei are moving slower' is also given as the reason for smaller probability for fusion. **Examiner's Comments** Most candidates wrote a great deal but the key physics was often omitted. Only a small number of high-scoring candidates realised that the helium nucleus had greater charge. This meant a greater repulsive electrostatic force between the helium nuclei and deuterium nuclei and hence a smaller chance of fusion between helium-deuterium nuclei. The most common misconception was that *'the greater mass of helium nuclei means that they are travelling slower and hence less chance of fusion'*.
			Total	10	

Question			Answer/Indicative content	Marks	Guidance
9		i	$R = \frac{4.9 \times 10^{-7} \times 5.0}{\pi \times (0.06 \times 10^{-3})^2}$ or R = 217 (Ω)	C1	**Note** : An incorrect equation here for A prevents this and any subsequent marks.
		i	time constant = 0.010 × 217	C1	
		i	time constant = 2.2 (s)	A1	**Allow** 2 marks for 0.54 (s) - diameter of 0.12 mm used instead of radius 0.06 mm. **Examiner's Comments** Most candidates picked up two or more marks in this synoptic question. Most candidates correctly used the resistivity equation to first determine the resistance of the bundle of wire and then the time constant of 2.2 s for the circuit. A very small number of candidates used ρ = 8900 for the resistivity of the metal instead of ρ = 4.9×10^{-7} Ωm. This was taken as a monumental error of physics and prevented the candidates from picking up any marks in this question.
		ii	Electrons are removed from **X** or electrons are deposited on **Y**.	B1	**Allow** electrons move anticlockwise (in the circuit).
		ii	**X** becomes positive or **Y** becomes negative	B1	There is no ecf from the previous B1 mark.
		ii	(The size of charge is the same because) an equal number of electrons are removed and deposited (on the plates).	B1	**Examiner's Comments** There was a good spread of marks, with many candidates scoring two or more marks. Most candidates did explain the charging of the two plates in terms of the flow of electrons in the circuit. Most candidates realised that the electrons would gather at plate **Y** giving it a negative charge. However, many could not adequately explain why the plates acquired equal but opposite charges. A significant number of candidates, mainly at the top-end, had no problems and gave superb answers in terms of equal number of electrons deposited and removed from the two plates.
		iii	$E = ½ \times 0.010 \times 12^2$ or E = 0.72 (J)	C1	

Question			Answer/Indicative content	Marks	Guidance
		iii	m = 8900 × [π × (0.06 × 10^{-3})^2 × 5.0] or 5.0(3) × 10^{-4}(kg)	C1	**Note** : An incorrect equation here for m or V prevents this and any subsequent marks.
		iii	5.03 × 10^{-4} × 420 × Δθ = 0.72	C1	Correct substitution into $mc\Delta\theta$ = 0.72; **allow** any subject.
		iii	increase in temperature = 3.4 (°C)	A1	**Note** : Do not penalise using diameter here again if already penalised in **(i)**. **Examiner's Comments** The majority of candidates scored full marks. Answers were well-structured and showed excellent synoptic knowledge of specific heat capacity. A significant number of candidates struggled when calculating the volume and hence the mass of the bundle of wire. Some candidates used $V = \frac{4}{3}\pi r^3$ to determine the volume of the wire. Such elementary errors are unjustifiable at this level.
		iv	Energy or V^2 increases by a factor of 4.	B1	**Allow** the label E or W for energy.
		iv	The (change in temperature) increases by a factor of 4 (because $\Delta\theta \propto E$).	B1	**Allow** Δθ = 13.6 (°C) for this B1 mark - possible ecf from **(iii)**. **Examiner's Comments** This question discriminated well with the majority of the candidates realising that the increase in the temperature would be four times greater. The explanations were often correct and elegantly presented in terms of energy ∝ p.d^2 for the energy stored in the capacitor. A small cohort of candidates gave qualitative answers and took no account of the potential difference doubling.
			Total	12	

Question			Answer/Indicative content	Marks	Guidance
10			($\frac{1}{2} m v^2 = \frac{3}{2} kT$) $\frac{1}{2} \times 6.6 \times 10^{-27} \times v^2 = \frac{3}{2} \times 1.38 \times 10^{-23} \times 10^8$ speed = 7.9×10^5 (m s^{-1})	 C1 A1	 **Allow**: KE ≈ *kT;* this gives an answer of 6.47×10^5 (m s^{-1}) **Examiner's Comments** The answers to this question were generally well-structured and easy to follow. Most candidates were familiar with the equation $E_k = 3kT/2$. A small number of candidates scored no marks for using either using 4.53×10^{-12} J or 1.13×10^{-12} J as the mean kinetic energy of the helium nuclei. The modal mark for this question was two.
			Total	2	

Question			Answer/Indicative content	Marks	Guidance
11		i	number per second = $4.8 \times 10^{-3}/1.6 \times 10^{-19}$	M1	**Note**: This must be seen to gain a mark **Examiner's Comments** Most candidates scored a mark for dividing 4.8×10^{-3} by 1.6×10^{-19}. A small number used a slightly longer route to show that the number of electrons incident at the anode was 3.0×10^{16} s^{-1}. They calculated the total power dissipated using the potential difference and current and then divided the power by the energy gained by each electron (2.4×10^{-14} J).
		i	number per second = 3.0×10^{16} s^{-1}		
		ii	(incident power =) $150 \times 10^3 \times 4.8 \times 10^{-3}$ or (incident power =) $3.0 \times 10^{16} \times 150 \times 10^3 \times 1.6 \times 10^{-19}$	C1	**Note** an incident power of 720 (W) scores this C1 mark
		ii	*($P = mc[\Delta\theta/\Delta t]$)* $0.99 \times 720 = 0.0086 \times 140 \times [\Delta\theta/\Delta t]$	C1	
		ii	rate of temperature increase = 590 (°C s^{-1})	A1	**Note**: Answer to 3 sf is 592 (°C s^{-1}) **Allow**: 2 marks for 598 (°C s^{-1}) or 600 (°C s^{-1}); 99% omitted **Allow**: 2 marks for 1.97×10^{-14} (°C s^{-1}); 3.0×10^{16} omitted **Examiner's Comments** The answers were generally easy to follow. The modal range for this question was two to three marks. The best candidates gave brief and flawless answers. Some candidates lost a mark for • premature rounding of numbers within the calculation; • failing to convert the mass into kg; • subtracting 273 K from the correct answer.
		iii	(photon energy = maximum KE of electron)		
		iii	$E = 150 \times 10^3 \times 1.6 \times 10^{-19}$ or $E = 2.4 \times 10^{-14}$ (J)	C1	**Allow**: $E = 720/3.0 \times 10^{16}$

Question			Answer/Indicative content	Marks	Guidance
		iii	$2.4 \times 10^{-14} = \dfrac{6.63\times10^{-34}\times3.0\times10^{8}}{\lambda}$ (Allow any subject)		
		iii	wavelength = 8.3×10^{-12} (m)	A1	**Allow**: 1 mark 8.3×10^{-10} (m); $E = 2.4 \times 10^{-16}$ (J) used **Examiner's Comments** The more able candidates performed well in this question. The energy of a single photon was equal to the maximum kinetic energy of a single electron. The omission rate was noticeably high for candidates in the lower quartile. The most common errors made were using mc^2, 1.6×10^{-19} J and 720 J as the energy of the photon. A small number of candidates tried to use the de Broglie equation to determine the shortest wavelength of the X-rays.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
12			**Diagram showing** • Oil in (insulated) container • Electrical heater fully immersed in oil • Thermometer / Temperature sensor	B1	**Not:** oven or hotplate **Allow:** 'Fully immersed' seen in the body of text **Thermometer / Temperature sensor** must be spelled correctly on diagram
			Electrical circuit • Ammeter in series, voltmeter in parallel with heater / joulemeter in parallel with heater • Power supply /+ & - signs marked on wires	B1	All elements should be shown to score these diagram marks. Ignore appropriate additional items Connections to heater should be clear.
			Measurements • Measure mass of oil / use known mass of oil, • Measure change in temperature / initial and final temperatures • Measure current, pd and (fixed) time / energy	B1	Must have all elements. **Allow:** Use of symbols **Allow:** Take energy reading from joulemeter **Not:** use given power rating of heater
			Calculation Input Energy = $E = Pt = VIt$ and $c = \frac{E}{m\Delta\vartheta}$	B1	Input energy must be consistent with equipment used. c must be the subject of the equation and temperature **rise** ($\delta\$$ or $\$_2 - \$_1$) must be clear. **Allow**: Draw graph of temperature against time $c = VI$ / [gradient × mass]

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Uncertainties Any **two** together with minimising action. • Heat losses (make *δ$* uncertain) – minimise by using initial *$* below and final *$* same amount above, room temperature • Temperature varies throughout oil – minimise by stirring before taking temperature readings • Some energy is required to raise temperature of the container / heater (etc) – allow by including in calculation. • Temperature will continue to rise after heater is turned off - find max temperature.	2 × B1	These points may be scored in the description of method. No credit for other uncertainties including heat lost to surroundings **Examiner's Comments** The vast majority of answers to this question were disappointing, to say the least. There are only two experiments specifically mentioned in the Specification and good answers were expected as a result. The question specifically asked for a labelled diagram and it was expected that this should be clear and carefully drawn with a suitable circuit using accepted symbols. Unfortunately most diagrams were too small, poorly drawn attempts at a 3d picture with incorrectly placed components. This immediately reduced the mark of all but the best candidates. Bunsen burners were also seen in several diagrams despite the wording of the question. The majority were able to score marks for the measurements and calculation although the logical sequence was often unclear. Those using bullet points generally scored better marks. At A2 level, heat loses to the surroundings should automatically be minimised by the use of insulation and lids for liquids. As a result no credit was allowed in the uncertainties for this response. It was realised that few were showing insulation in their diagrams or labelling and allowance was made in allocating the apparatus mark.
			Total	6	

Question			Answer/Indicative content	Marks	Guidance
13	a	i	Molecules (of the liquid) are in random / haphazard motion (AW)	B1	Not zig-zag
		i	Molecules (of liquid) are smaller than pollen grains	B1	must compare to pollen grains **Ignore** mass is smaller **Examiner's Comments** Although there were many good answers to this basic question on Brownian motion a significant number of candidates failed to score the second marking point in (i).
		ii	Increase the temperature (of the liquid)	B1	**Allow:** Heating the liquid
	b	i	Any **three** from: • Collisions with the walls / container / sides are elastic	B1	**Collision / collides** must be spelled correctly to score the mark Ignore collisions between gas molecules
		i	• force between molecules is negligible / zero except during collisions	B1	
		i	• Volume of the molecules is negligible compared to the volume of the container (AW)	B1	Must refer to comparison to score either of the last two points. Ignore references to incomplete assumptions and assumption
		i	• Time within a collision is negligible compared to time between collisions	B1	not given in expected answer.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	Max 3	B3	**Examiner's Comments** Given that the random motion of the molecules had been established in (a) it was decided not to include this in the list of critical assumptions detailed in the mark scheme. The mark scheme required specific references to the 'only collisions' considered at this level and comparisons in the references to volumes and times. Candidates were not penalised for giving extra details or additional assumptions. As a result the question discriminated well with the more able candidates scoring at least 2 marks while most were able to score 1 mark. Kinetic theory of gases is the major application of Newton's laws to the microscopic world of molecules that is considered in the Specification. This question, although similar to the question set in January 2012, focused the candidate's attention towards Newton's laws. The mark scheme was slightly tightened from the one used in 2012 by the addition of specific references to thewalls and molecules.
		ii	Momentum of the molecule changes when it collides with the wall (AW)	B1	**Allow:** There is an impulse on molecule when it collides with wall.
		ii	Force on the molecule is rate of change of momentum (by N 2nd Law)	B1	
		ii	(By N 3^{rd} Law) Force on wall is equal to and opposite to the force on the molecule	B1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	pressure = $\frac{\textbf{sum of forces (due to all molecules)}}{\text{Area of wall}}$	B1	**Examiner's Comments** There is a clear logical sequence to the application of Newton's laws to the explanation of the existence of gas pressure. Unfortunately this was rarely conveyed by candidates in their answers. Many jumped straight from change in momentum of the molecules, to the force on wall with no reference to the laws involved. It was rare to see an answer in which the candidate had realised that the observed pressure was in fact the sum of a large number of individual forces acting on the area of the wall. Far too many expected to score the mark with the simplistic P = F/A formula. On the whole this was a disappointingly, poorly answered question where only the most able were capable of demonstrating a reasonable understanding of the theory.
	c		$\rho = \frac{m}{V}$ (any subject) $n = \frac{m}{M}$ (any subject) $pV = nRT$ $p\left(\frac{m}{\rho}\right) = \left(\frac{m}{M}\right)RT$	M1 M1 A1	**Allow:** $\rho = \frac{m}{V}$ (M1) A clear statement of "n = 1 then m = M" (M1) **Note:** Both M marks must be scored and the method **must be clear** to score the A1 mark. $pV = nRT$ $p\left(\frac{M}{\rho}\right) = RT$ (A1) $p = \frac{\rho RT}{M}$ (A0)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			$p = \frac{\rho RT}{M}$	A0	**Examiner's Comments** This difficult question allowed the more able candidates to display their logical presentation in a show question designed to give a hint to candidates for Q6d. Many were able to score the first mark but were unable to score the subsequent marks. Many candidates did not draw a clear distinction between the symbols and n was often set to 1 for no reason other than to remove it from the equation. Those who showed a clear distinction between m and M fared much better. A few candidates introduced their own notation to aid themselves and this was, of course, accepted by the examiners.
	d	i	Use of $p \propto \rho T$ or $\frac{p_T}{p_B} = \frac{\rho_T T_T}{\rho_B T_B}$	C1	**Allow:** any subject
		i	$0.35 = \frac{\rho_T \times 240}{1.3 \times 293}$ $\rho_T = \frac{0.35 \times 1.3 \times 293}{240}$	C1	**Allow:** any subject **Allow:** Max 1 mark if temperatures are not converted to kelvin. Expect density to be – 0.276 kg m^{-3}
		i	$\rho_T = 0.56$ (kg m^{-3})	A1	Answer to 3 sf is 0.555 (kg m^{-3}) **Examiner's Comments** This stretch and challenge question clear gave many candidates some difficulty. Many used the gas laws in PV/T form correctly and eventually arrived at the correct answer. Only a small number realised that they could use the expression given in (c) to formulate an equation relating P to ρT saving a considerable amount of time and effort.
		ii	**Correct** use of $N \propto \frac{p}{T}$ or $\frac{N_T}{N_B} = \frac{p_T T_B}{p_B T_T}$ $\frac{N_T}{N_B} = \frac{0.35 \times 293}{240}$ $\frac{N_T}{N_B} = 0.43$	C1	Do not penalise use of °C if already penalised in (i) **Allow:** Alternative approach using $\frac{N_T}{N_B} = \frac{\rho_T}{\rho_B}$ with possible ecf from (i)

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$\frac{N_T}{N_B} = \frac{0.35 \times 293}{240}$ $\frac{N_T}{N_B} = 0.43$	A1	Answer to 3 sf is 0.427 **Examiner's Comments** Given the difficulty shown in arriving at the correct answer to (i) it was pleasantly surprising to see the quite large number of candidates scoring marks in (ii) using the ratio of densities even though a few inverted the ratio and failed to spot the illogicality of their answer.
			Total	18	
14			P = (m/t)cθ = 0.070 × 4200 × (30 – 14) = 4700 unit = W or J s^{-1}	C1 A1 B1	 or 4.7 **allow** kW if consistent with the value for P.
			Total	3	

Question			Answer/Indicative content	Marks	Guidance
15		i	Fission reactors produce radioactive by-products which affect future generations and the environment in terms of possible contamination / exposure to humans and animals.	B1	
		ii	No of particles in 1000 g U = 1000/235 × 6.02 × 10^{23} = 2.56 × 10^{24} No of reactions for U = 2.56 × 10^{24}	B1	Appreciate that the key to the answer is the difference in numbers of atoms / nuclei **or** equal number of nucleons involved scores one mark if nothing else achieved.
		ii	Energy from U = 2.56 × 10^{24} × 200 = 5.12 × 10^{26} MeV	B1	
		ii	No of particles in 1000g H = 6.02 × 10^{26} No of reactions = 6.02 × 10^{26}/4 Energy from H = 6.02 × 10^{26}/4 × 28 = 42.14 × 10^{26} MeV	B1	
		ii	Hence energy 42/5 = 8.2 times higher	B1	
		ii	*second method* 235 g of U and 4 g of H / He contain 1 mole of atoms	or B1	
		ii	there are 4.26 moles of U and 250 moles of He	B1	
		ii	so at least 58 times as many energy releases in fusion ratio of energies is only 7 fold in favour of U	B1	
		ii	therefore 58/7 times as much energy released by 1 kg of H	B1	
		ii	*similar alternative argument,* e.g. For U each nucleon 'provides' 0.85 MeV	B1	
		ii	For H each nucleon 'provides' 7 MeV	B1	
		ii	(Approx) same number of nucleons per kg of U or H	B1	

Question			Answer/Indicative content	Marks	Guidance
		ii	so 8.2 times as much energy from H	B1	
			Total	5	
16	a		when pressure or volume of an ideal gas tends to zero, the temperature must tend to zero; the temperature scale with this zero of temperature is the kelvin scale / AW	B1 B1	
	b		pV/T = constant $(1.0 \times 10^5 V)/290 = (1.0 \times 10^3 \times 1.0 \times 10^6)/230$ $V = 1.26 \times 10^4$ (m^3)	B1 B1 B1	
	c	i	$n = pV/RT = 1.0 \times 10^5 \times 1.26 \times 10^4/(8.31 \times 290)$	B1	ecf
		i	$n = 5.2 \times 10^5$	B1	allow 5.4×10^5 using 1.3×10^4
		ii	$4.0 \times 10^{-3} \times 5.2 \times 10^5 = 2.1 \times 10^3$ (kg)	B1	ecf (i)
	d		(internal energy ∝ T) E = 1900 × 230/290 = 1500 (MJ)	B1	
	e		$U = \rho Vg = 1.3 \times 1.26 \times 10^4 \times 9.81 = 1.61 \times 10^5$ Ma = U – Mg $27 M = 1.6 \times 10^5 - Mg$ giving $M = 4.3 \times 10^3$ kg	C1 C1 A1	or $1.3 \times 1.3 \times 10^4 \times 9.81 =$ 1.66×10^5 $M = 4.6 \times 10^3$ kg
			Total	12	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
17	a		GPE converted in one inversion = 0.025 × 9.8 × 1.2 (= 0.294)	C1	
			GPE converted in 50 inversions = 0.294 × 50 = 14.7 (J)	A1	
			(Use of $Q = mc\Delta\theta$ to give) 14.7 = 0.025 × c × 4.5	C1	**Allow** follow through from their total GPE converted
			c = 130 (J kg^{-1} K^{-1})	A1	**Note** answer to 3 sf = 131 (J kg^{-1} K^{-1}) **Examiner's Comments** Despite the poor start in (a) the vast majority scored highly in this part, indicating that candidates were well aware of the underlying physics in this experiment. Only a small number converted the rise in temperature into 277.5K which was a pleasing improvement on previous years.
	b		• No heat is absorbed by the tube/ lost (by conduction) through the tube/all heat goes to pellets	B1	**Ignore** 'heat lost to surroundings/air' **Examiner's Comments** The rather vague 'heat lost to surroundings' response was commonly seen.
			• All the lead falls through the same height or length of tube/ Lead does not bounce on impact	B1	
	c		Temperature change is the same	M1	

Question			Answer/Indicative content	Marks	Guidance
			(Since mass is doubled) (max) GPE/KE/total energy is doubled **AND** Q is doubled	A1	**Allow** mgh = mcΔθ and m is same **or** m cancels **Alternative answer** **Allow** 2 marks for any sensible practical suggestions why T is **not** the same eg double mass means more lead which will **not** fall full length of tube. **Examiner's Comments** The explanation of the physics involved in this experiment caused much difficulty even to able candidates. A significant number thought that the temperature rise was proportional to the gravitational potential energy and lost both marks.
			Total	8	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
18	a		An ideal gas has zero/negligible (electrical) PE / All internal energy is (translational) KE	B1	
			(translational) KE ∝ absolute/ thermodynamic /kelvin temperature	B1	**Allow** internal energy ∝ absolute/ thermodynamic /kelvin temperature Note: absolute/thermodynamic/kelvin must be used and spelled correctly for second mark **Examiner's Comments** The majority of candidates did not appreciate that this question was limited to ideal gases and consequently consideration of changes in potential energy of the molecules was inappropriate. This resulted in the loss of the first mark. The second mark was also rarely scored because candidates did not specify clearly that the temperature of the gas must be measured on the kelvin scale. This important distinction in the temperature scales appeared to have been unwisely assumed by the majority of candidates since most were aware that it was necessary to convert to kelvin scale in the calculations that followed.
	b	i	Number of moles of helium = 80/0.004 (= 2 × 10^4)	C1	
		i	$V = \frac{nRT}{p} = \frac{2 \times 10^4 \times 8.31 \times 294}{1.0 \times 10^5}$	C1	**Allow** use of $pV=NkT$ Use of T in °C is WP giving max 1 out of 3
		i	V = 490 (m^3)	A1	**Allow** follow through(FT) from an error in n **Examiner's Comments** This calculation was generally well answered with a clear layout. Only rarely were errors seen in the determination of the number of moles of helium or in the appropriate temperature of the gas.

Question			Answer/Indicative content	Marks	Guidance
		ii	number of moles remaining $= \frac{pV}{RT} = \frac{1.2\times10^3 \times 1.4\times10^4}{8.31\times233}$ $= 8.68 \times 10^3$	C1	Use of T in °C is WP 0/2
		ii	Number of moles escaping = $2 \times 10^4 - 8.68 \times 10^3$ $= 1.1 \times 10^4$	A1	**Examiner's Comments** The number of moles remaining in the balloon was determined accurately by almost all candidates. Some, however, unfortunately overlooked the fact that the question asked for the number escaping and left their answer as 8700 mols.
			Total	7	
19			D	1	
			Total	1	
20			C	1	
			Total	1	
21			B	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
22	a		The energy required per unit mass to change the temperature by 1 K / 1°C.	B1	**Allow**: $c = E/m\,\Delta\theta$, where E = energy, m = mass and $\Delta\theta$ = change in temperature.
	b	i	$E = m \times c \times \Delta\theta = 0.15 \times 4200 \times 55$ $E = 3.5 \times 10^4$ (J)	A1	**Note** answer to 3 s.f. is 3.47×10^4 (J)
		ii	(Energy transferred from water = energy transferred to glycerol) $0.150 \times 4200 \times (75 - \theta)$ or $0.020 \times 2400 \times (\theta - 20)$	C1	
		ii	$0.150 \times 4200 \times (75 - \theta) = 0.020 \times 2400 \times (\theta - 20)$	C1	
		ii	$\theta = 71$(°C)	A1	
		iii	The temperature is less / different because of thermal energy of the water is also used to warm up the boiling tube. (AW)	B1	
	c		Graph showing constant temperatures during phase changes.	B1	
			Temperature increases linearly for the solid and the liquid.	M1	
			Steeper slope for the solid state.	A1	
			Total	9	

Question			Answer/Indicative content	Marks	Guidance
23		i	$-mV_g = ½mv^2$ or $½mv^2 + mV_g = 0$	B1	
		i	$V_g = -GM/R = -gR$	B1	
		i	$v = \sqrt{(2gR)}$	B1	Working must be shown
		ii	$v = \sqrt{(2 \times 9.81 \times 6.4 \times 10^6)} = 11 \times 10^3$ m s^{-1}	B1	allow 11(.2) km s^{-1}
		iii	$½mc^2 = 3/2\ kT$ where $m = (M/N_A) = 6.6 \times 10^{-27}$ kg	B1	**ecf (ii); allow** m = 4u or $4 \times 1.67 \times 10^{-27}$
		iii	$T = 6.6 \times 10^{-27} \times 121 \times 10^6 / 3 \times 1.38 \times 10^{-23}$	C1	
		iii	$T = 1.9 \times 10^4$ (K)	A1	**allow** 2 or 2.0
		iv	1 random motion and elastic collisions of particles	B1	**max** 4 out of 5 marking points where answer is a logical progression
		iv	2 lead to distribution of kinetic energies/velocities among particles	B1 B1	
		iv	3 a very few will have very high velocities at top end of distribution 4 a long way from mean /r.m.s. velocity at 300 K 5 hence some able to escape	B1	
		v	helium nucleus is an α-particle	B1	**max** 2 out of 3 marking points
		v	so helium is generated by radioactive decay helium is found in (natural gas) deposits underground	B1	
			Total	**13**	

Question			Answer/Indicative content	Marks	Guidance
24	a		$E = \frac{6.63 \times 10^{-34} \times 3.0 \times 10^{8}}{1.1 \times 10^{-6}}$ $E = 1.8 \times 10^{-19}$ (J)	B1 A0	Values must be substituted Answer to 3sf is 1.81×10^{-19} (J) **Examiner's Comments** This question was specifically included to give a hint as to the method to be used in (b). The question was written in a 'show' format to enable candidates to answer (b) even if they could not recall this area of synoptic work. However this did mean that all working, including substitution, had to be shown and this did result in a small number losing the mark.
	b		$m = pV = 8.1 \times 10^{-12} \times 4.5 \times 10^{3} = (3.645 \times 10^{8})$ Thermal energy gained = *(mc Δθ)* = $3.645 \times 10^{-8} \times 520 \times [1700 - 20]$ (= 0.0318) $1.81 \times 10^{-19} \times 6.3 \times 10^{19} \times t = 0.0318$ $t = 2.8 \times 10^{-3}$ (s)	C1 C1 A1	 **Allow:** ecf from (a) and mass of titanium **Examiner's Comments** Again this question had three distinct strands to the physics. The vast majority of candidates were capable of determining the correct mass and thermal energy required to raise the temperature of the titanium. A small number of errors were seen in these two strands however: mainly in transposition of the density formula and converting temperature changes incorrectly to kelvin scale. The final stage to determine the time was less confidently handled with transposition errors and some strange manipulation of the equations which usually resulted in the reciprocal of the correct answer. Perhaps the very small time involved in this form of welding surprised a few candidates.
	c		Thermal energy is conducted / transferred to the rest of titanium / metal	B1	**Not:** heat lost to surroundings

Question			Answer/Indicative content	Marks	Guidance
			Photons are reflected / scattered from / not absorbed the titanium surface	B1	**Examiner's Comments** The answers given for this question were disappointing. All too often the only factor quoted was the vague '*heat lost to the surroundings'*. A significant number of candidates scored one mark by identifying the loss of thermal energy to the non-shaded volume of titanium. Only a tiny minority realised that some photons would be reflected from the metal surface. Other suggestions such as *'photons are absorbed in the air', 'photons would miss the target', 'not all photons have the same energy', 'the laser needs to heat up as well'* were not given any credit. Marks for this discriminating question were mostly awarded only to the more able candidates.
	d		(Photon) energy is converted into potential energy (rather than kinetic energy) OR Energy is used to change solid to liquid / phase (rather than increase kinetic energy) OR Energy provides (specific) latent heat of fusion (rather than increase kinetic energy)	B1	**Allow:** energy is used to overcome the forces between atoms / breakdown the crystal structure of titanium (rather than increase kinetic energy) **Examiner's Comments** This question discriminated across the entire spectrum of ability, largely as a result of candidates writing about the lack of a temperature change rather than focusing on what actually happened to the energy supplied at this stage. Many answers were merely statements lacking in the vital explanation. It was, however, encouraging to see that the physics involved in this unfamiliar situation was broadly understood by the candidates.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
25			C	1	Examiner's Comments In this question, candidates should consider the equation pV = nRT. If the pressure and volume remain the same, this gives nT as a constant also. If the number of particles decreases to two thirds of the original number, then the temperature in kelvin, and thus the total kinetic energy and hence mean square speed must have increased by a factor of 1.5, giving option C. This question provided opportunities for middle-grade candidates.
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
26	a		Use a thermometer (with ± 1 °C) Stir water bath / avoid parallax (for glass thermometer)	B1 B1	**Allow** 'temperature sensor / gauge' **Allow** 'avoid touching sides of water bath with thermometer' **Allow** 'take temperature in several places / times and average' **Allow** idea of 'leave thermometer for long time (to reach thermal equilibrium)' **Not** idea of 'use thermometer with finer resolution' **Examiner's Comments** A large majority included a correct measuring device, such as a thermometer. Significantly fewer described a technique for accurate measurements such as stirring the water or taking the temperature at several points and calculating a mean temperature.
	b	i	Smaller (spacing between) divisions / increments (AW)	B1	**Ignore** any reference to accuracy or precision **Allow** 'less uncertainty' **Allow** better or smaller or greater or higher resolution **Examiner's Comments** Approximately half of the candidature made a correct comment regarding resolution or that the smaller intervals on the psi scale made it a sensible choice of scale.
		ii	$p = 37.0 \times 4.448 / (1000 \times 0.0254^2)$ 255 (kPa) uncertainty = 3 (kPa)	 B1 B1	**Allow** clearly identified correct answer in table or in working area. Must be 3sf Must be 1sf **Allow** 255.1 ± 3.4 scores mark 1 **Examiner's Comments** The vast majority of candidates correctly calculated the pressure in kPa and stated that the absolute uncertainty was 3 kPa. A very small number of responses were rounded inappropriately.

Question			Answer/Indicative content	Marks	Guidance
	c	i	Point plotted at (44, 255)	B1	ECF from **(b)(ii)** Plot to with ± half a small square **Ignore** checking error bars **Examiner's Comments** Most candidates correctly plotted the point with error bars. In this instance during marking Examiners were instructed to ignore the error bars as they were too difficult to view when scanned.
		ii	**Level 3 (5–6 marks)** Clear explanation, description **and** determination *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation, description **and** determination Or Some explanation and clear determination *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation or description or determination *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.* **0 marks** No response or no response worthy of credit.	B1 × 6	**Indicative scientific points may include:** **Explanation and Description** • Absolute zero is the minimum possible temperature / at absolute zero KE is zero • At absolute zero *p* is zero • At absolute zero, the internal energy is minimum (allow 0) • Absolute zero should be (about) –273 °C • Reference to $pV = nRT$ or $pV = NkT$ or $p \propto T$ • A graph of *p* against θ is a straight line / straight line drawn on graph • Intercept of straight line with *x*-axis or θ-axis is absolute zero calculated by using y= mx + c **Determination** • Gradient in the range 0.7 to 0.9 (kPa K^{-1})

Question			Answer/Indicative content	Marks	Guidance
					• *y* = *mx* + *c* used to determine the intercept *c* or absolute zero • Absolute zero in the range –320 °C to –240 °C Use only L1, L2 and L3 in RM Assessor. **Examiner's Comments** It was clear that the majority of candidates had either performed this experiment themselves or had otherwise seen it before. The concept of absolute zero was very successfully described and many knew that an extrapolation or calculation involving the equation of a straight line was required to find absolute zero as the x-intercept of the straight line. Common errors included mis-calculating the gradient, inability to rearrange the equation or inappropriate conversion to kelvin. Re-plotting the graph was not required and merely wasted time for little reward.
	d		Draw the worst fit line (through all the error bars) (AW). Determine the new value for absolute zero and find the difference between the value in **(c)(ii)** and this new intercept. (AW)	**B1** **B1**	**Examiner's Comments** Many candidates realised that drawing a line of worst fit was sensible. Far fewer were clear that using the line of worst fit to find a new x-intercept, leading to a spread in values for absolute zero was the correct procedure. Many incorrectly suggested finding the difference in gradients, or percentage differences in gradients.

Question			Answer/Indicative content	Marks	Guidance
	e		Cooling gas value of absolute zero is lower than **(c)(ii)**	B1	
			(Whilst cooling, the) temperature of gas lags behind the temperature of water (AW, ORA)	B1	
			Graph is shifted to the left	B1	**Allow:** gradient is too shallow **Allow:** *p* measured is higher than expected for incorrect measurement of *T* (so affects the graph) (AW, ORA)
			Stir water / <u>wait</u> for temperatures to be the same / attempt at measuring temperature of gas directly (AW)	B1	**Not** insulation of water bath **Not** heat losses **Examiner's Comments** The first mark for this item was intended to be for a straightforward comparison that the repeated experiment yielded a lower value than that from part **c(ii)**. Many candidates calculated a percentage difference yet did not refer to the direction of difference. Some candidates successfully suggested that the water would always be cooler than the gas and so the thermometer reading would be systematically lower than the true temperature of the gas. Rather fewer discussed that the pressure reading would therefore be higher than it should be for the thermometer reading. Very few candidates linked this idea to the effect on the graph, namely that the points would all be shifted to the left, causing a lower x-intercept or a less steep line of best fit. There were three acceptable experimental approaches to avoid this systematic error. Stirring the water and waiting until the gas and water equilibrated would have reduced the effects of the rapid cooling. A sensible approach employed by some candidates was to take the temperature of the gas directly using a thermometer or temperature inside the flask.
			Total	18	

Question			Answer/Indicative content	Marks	Guidance
27			Energy used to heat water to 100 °C = 0.60 × 4200 × 80 (= 201.6 kJ)	C1	
			Energy remaining to vaporise water = 528 (kJ) – 201.6 (kJ) (= 326.4 (kJ)	C1	Possible ecf from **(a)**
			mass vaporised = 326.4 × 10^3 / 2.3 × 10^6 = 0.1419 (kg)	C1	
			mass of water left = 0.60 – 0.1419		
			mass of water left = 0.46 (kg)	A1	
					Examiner's Comments This was a challenging multi-step calculation that differentiated between the candidates well. A method employed by many high-scoring candidates began with a word equation "Total energy transferred = energy required to heat water to boiling point + energy required to vaporize water". This made it clear to award the mark for substituting into the specific heat capacity equation and clear to the candidate how to find the mass of vaporized water. A minority of candidates forgot to subtract the mass of vaporized water from the initial mass.
			Total	4	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
28	a		The sum of (the random distribution of) the KE and PE of (its) molecules	B1	**Not** if no clear indication of particulate nature, i.e. allow particles or atoms for molecules **Examiner's Comments** The correct answer for this item was a direct reference to specification point 5.1.2 (d) and required the association with the particles of a system. Many more than half of the candidates would have scored this mark had they included this association.

Question			Answer/Indicative content	Marks	Guidance
	b		No change in KE	M1	**Allow** 'KE is not changing' **Not** 'KE is not increasing'
			because temperature is constant (during melting)	A1	
			PE of (the molecules) increases (during melting)	M1	
			The internal energy increases	A1	**Note:** This A1 mark can only be scored if both M1 marks have been awarded. **Examiner's Comments** This question was designed to lead the candidates into thinking about both KE and PE of the particles contained within the paraffin. The stem of the question includes a reference to constant temperature, so credit could only be awarded to linking this idea to that of the molecules' constant average KE, since average KE is directly proportional to absolute temperature. KE not changing was an acceptable alternative wording to constant average KE, but 'KE not increasing' was not. Candidates often picked up a mark for correctly stating that the PE of the molecules increased but would only gain the final mark for stating that the internal energy increased if they had already got the correct ideas for both PE and KE. Examiners commented that some candidates assumed conservation of energy and so if PE went up then KE went down or vice versa. Candidates wasted time and effort by describing what happened either before or after melting, which was not required.
			Total	5	

Question			Answer/Indicative content	Marks	Guidance
29		i	KE = ½mv^2 **and** GPE = GMm / r ½$mv^2 = GMm / r$ then a valid step to $v = \sqrt{(2GM / r)}$	C1 A1	**Allow** m = 1 (kg) if clearly defined **Examiner's Comments** Examiners were delighted that candidates proved the relationship for escape velocity very clearly indeed with the higher ability candidates correctly suggesting that 'KE + GPE = 0' was the condition for escape, although 'KE lost = GPE gained' would have been a clear way of reconciling any minus sign confusion. A minority of candidates tried, unsuccessfully, to invoke the expression for circular motion inappropriately.
		ii	($v^2 = 2 \times 6.67 \times 10^{-11} \times 0.131 \times 10^{23} / 1.19 \times 10^6$) v = 1200 (m s^{-1})	A1	Answer to 3.s.f. is 1210 **Examiner's Comments** Approximately four-fifths of all candidates calculated the escape velocity on Pluto correctly. Those that did not score the mark for this item did so because of improper calculator use or, more rarely, because they selected the wrong data from the question.

Question			Answer/Indicative content	Marks	Guidance
		iii	Mercury has a higher escape velocity than Pluto (ORA)	B1	**Allow** a supporting calculation (speed is about 4.2 km s^{-1})
			Mercury is closer to sun **and** Mercury is hott<u>er</u> (ORA)	M1	
			Molecules on Mercury (are more likely to) have **speed** higher than the escape velocity	A1	**Allow** 'required speed' for 'escape velocity' **Allow** 'fast enough to escape' **Examiner's Comments** Candidates found this last item very challenging indeed, with only exceptional candidates gaining two or three marks. Many candidates suggested that the reason for Mercury's lack of atmosphere was the superior gravitational pull of the Sun, which is wholly incorrect. Others suggested that the solar wind or 'radiation' had burnt off the atmosphere. Rather fewer candidates correctly related Mercury's smaller mean distance to the Sun and its higher temperature or reasoned that Mercury's escape velocity was higher than Pluto's. Only a small minority of candidates recognised that even though Mercury has a higher escape velocity, its higher temperature gave the atmosphere's molecules a higher average speed which would have exceeded Mercury's escape velocity.
			Total	6	

Question			Answer/Indicative content	Marks	Guidance
30		i	sin **or** cos wave with 1.5 wavelengths (between **C** and **R**) y-axis showing scale, i.e. (amplitude) $2.(0) \times 10^{-6}$ (m) correct scale on x-axis showing $\lambda = 0.2$ (m) **X** and **Y** labelled at adjacent intercepts on x-axis	**B1** **B1** **B1** **B1**	 unit must be present, e.g 10^{-6} m **NOT** if axis labelled time **Examiner's Comments** Most candidates correctly labelled the scale on the displacement axis of the sinusoidal graph that they drew. The points where the air particles were moving the fastest were also well known. Fewer labelled *distance* on the x-axis, many incorrectly writing *time.* Only the better candidates marked the correct scale on this axis and very few indicated that there were 1.5 wavelengths between the points **C** and **R.**

Question			Answer/Indicative content	Marks	Guidance
		ii	1 $v = A\omega$ **or** $2\pi fA$ $v = (2 \times 10^{-6} \times 2 \times 3.14 \times 1.7 \times 10^{3} =)$ 2.1×10^{-2} (m s^{-1}.) 2 $½Mv^2 = 3/2\ RT$ and $T = 290$ $v = \sqrt{(3 \times 8.31 \times 290 / 0.029)}$ $v = 5(.0) \times 10^2$ (m s^{-1}.)	C1 A1 C1 A1	**or** $½mv^2 = 3/2\ kT$ so $v^2 = 3\ (k / m)\ 290$ **N.B. remember to record a mark out of 4 here** **Examiner's Comments** Answers were generally well structured into two sections, one for each experiment. A few candidates thought they could measure the wavelength on the oscilloscope screen. In experiment (a) most understood that the phase difference between the two oscillations at the microphone changed as one speaker was moved away. Explanations often muddled *path* and *phase* difference or referred to *nodes* and *antinodes* detected by the microphone. Some candidates misinterpreted the experiment moving the microphone to detect interference fringes, allowing the double slits formula to be used to find the wavelength. Others thought that Doppler shift was applicable. For experiment (b) many candidates used *maxima* and *minima* in place of *antinodes* and *nodes* although most recognised this to be a *standing* wave situation. Quite a few candidates ignored the instruction about reducing the uncertainty. The best candidates suggested reducing the frequency to reduce the percentage uncertainty in the wavelength measurement.
			Total	8	
31			A	1	
			Total	1	
32			B	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
33			D	1	Examiner's Comments The unit J mol^{-1} K^{-1} is the same unit as the molar gas constant, such that pV = nRT. It follows that the unit of R must be the same as the unit of pV/T as 'n' has no units.
			Total	1	

Mark Scheme

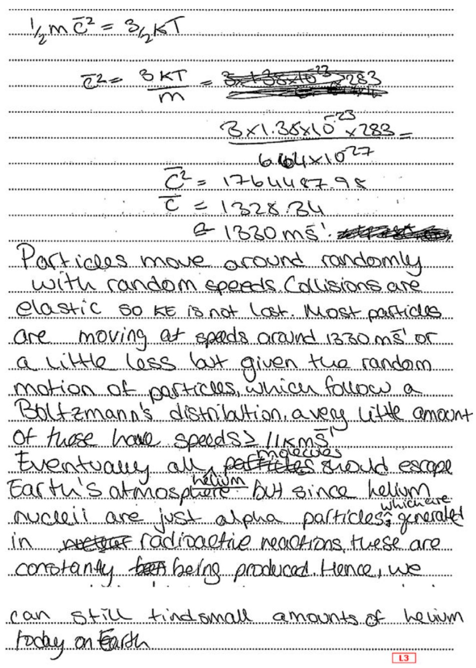
Question			Answer/Indicative content	Marks	Guidance
34			**Level 3 (5–6 marks)** Clear explanation and correct calculation. *There is a well–developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* **Level 2 (3–4 marks)** Some explanation and limited calculation, or limited explanation and correct calculation. *There is a line of reasoning presented with some structure.* *The information presented is in the most–part relevant and supported by some evidence.* **Level 1 (1–2 marks)** Limited explanation and missing or incomplete calculation. *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** No response (NR) or no response worthy of credit (0).	B1x6	Indicative scientific points may include: Explanation • At a certain temperature all atoms have the same <u>average</u> kinetic energy • Helium behaves as an ideal gas • $E_K = \frac{3}{2}kT$ • Mean / r.m.s speed of atoms is less than the escape velocity • Atoms have range of speeds / velocity or mention of Maxwell–Boltzmann distribution • Faster atoms have escaped the Earth (over long period of time) • Earth was significantly hotter in the (ancient) past Calculation • T = 283 K • $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ • $c_{r.m.s.} = \sqrt{\frac{3kT}{m}}$ • $c_{r.m.s}$ = 1.3 km s^{-1}

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance

<u>**Examiner's Comments**</u>

Exemplar 6


$\frac{1}{2}m\bar{c}^2 = \frac{3}{2}kT$

$\bar{c}^2 = \frac{3kT}{m} = \frac{3 \times 1.38 \times 10^{-23} \times 283}{6.64 \times 10^{-27}} =$

$\bar{c}^2 = 1764487.95$

$\bar{c} = 1328.34$

$\approx 1330\ ms^{-1}$

Particles move around randomly with random speeds. Collisions are elastic so KE is not lost. Most particles are moving at speeds around $1330\ ms^{-1}$ or a little less but given the random motion of particles, which follow a Boltzmann's distribution, a very little amount of those have speeds $\geq 11\ km s^{-1}$. Eventually all molecules should escape Earth's atmosphere but since helium nuclei are just alpha particles, which are generated in radioactive reactions, these are constantly being produced. Hence, we can still find small amounts of helium today on Earth.

L3

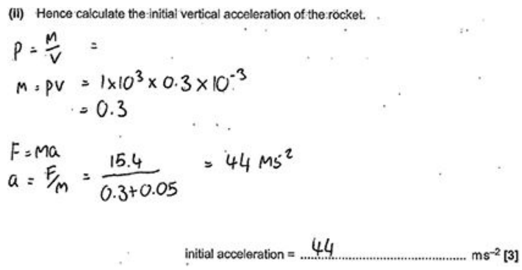
In correctly calculating the root means square speed and by being clear about how that has been calculated, this candidate has gained L2 already. There is a correct comparison of this speed with the escape velocity. There is also reference to the Boltzmann distribution of speeds, suggesting that even though a small fraction will have a sufficient velocity, over time those particles will escape.

Question			Answer/Indicative content	Marks	Guidance
					Most candidates made good progress with the calculation or provided an alternative by calculating the mean KE of a particle and comparing that with the KE a particle with escape velocity would have. A significant fraction made a poor comparison of their value with escape velocity (e.g. that 1300 ms^{-1} was greater than 11 km s^{-1}) or compared the mean squared speed with the escape velocity.
			Total	6	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
35	a		*n (= pV/RT)* = 2.4 x 10^5 x 1.2 x 10^{-3}/8.31 x <u>290</u> *n* = 0.12 (mol)	C1 A1	**Allow** any correct rearrangement of the equation **Allow** use of $pV = NkT$ and $n = Nk/R$ or **n =** **N**/NA (*n* = 0.1195)
	b		pV = constant (or $p_1V_1 = p_2V_2$) p_{final} = 2.4 x 10^5 x 1.2/1.5 = 1.9(2) x 10^5 (Pa)	C1 C1 A1	<u>Alternative method:</u> $p = nRT/V$ (*p* must be the subject) **Allow** use of $p = NkT/V$ (with $N = 7.2 \times 10^{22}$ and k = 1.38 x 10^{-23}) Substitute *p* = 0.12 x 8.31 x 290 / 1.5 x 10^{-3} ECF from 1a for incorrect *n* and/or *T* *p* = 1.9(3) x 10^5 (Pa) <u>**Examiner's Comments**</u> Questions 1(a) and 1(b) took the ideal gas equation and applied it to an unfamiliar situation, that of a toy rocket. Most candidates answered these questions well, remembering to convert the temperature from 17°C to 290K.
	c	i	Δp = (2.4 – 1.0) - 10^5 = 1.4 x 10^5 (Pa) upwards force *(= ΔpA)* = (2.4 – 1.0) x 10^5 x 1.1 x 10^{-4} = 15 (N)	C1 C1 A0	<u>Alternative method:</u> Downwards force (from trapped air) = *p*A = 2.4 x 10^5 x 1.1 x 10^{-4} = 26.4 (N) **and** upwards force (from atmosphere) = *p*A = 1.0 x 10^5 x 1.1 x 10^{-4} = 11.0 (N) So total upwards force = 26.4 – 11.0 = 15.4 (N) **Ignore** any attempt to calculate weight **Special case: Allow** 1/2 for the use of Δ*p* = 2.4 x 10^5 (Pa) giving upwards force = 26.4 (N) <u>**Examiner's Comments**</u> Most candidates realised that a difference in air pressure between the inside and outside of the bottle would force the water downwards, producing an upwards force on the bottle which could be calculated using p = F/A.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	m = 0.3 + 0.05 (= 0.35) (kg) (Resultant force = upwards force – W = ma) 15.4 – (0.35 x 9.81) = 0.35a **or** a = 12/0.35 a = 34 (m s^{-2})	C1 C1 A1	0.050 + (10^3 x 0.3 x 10^{-3}) Alternative approach: a = (15.4/m) - g ECF for incorrect value of m **No** ECF ci (since we are told that upwards force = 15(.4)(N)) Upwards force = 15 (N) gives a = 33 (m s^{-2}) **Examiner's Comments** This question, although a simple F = ma problem, challenged many candidates. **Exemplar 1**  Exemplar 1 shows the most common incorrect response. The correct value for mass (m = 0.35kg) has been used, but the value for the upwards force (15.4N) rather than the resultant force (15.4 – mg) has been used for F.
			Total	10	
36			C	1	**Examiner's Comments** As a substance melts, the PE of the molecules increases, ruling out answers B and D. The temperature of a melting substance does not change and so the KE of the molecules cannot change, as the temperature and mean KE of molecules are directly proportional. This means that C must be correct. A cannot be correct since the internal energy is the sum of the KE and PE of the molecules. The KE is constant and the PE increases, meaning the internal energy must also increase.
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
37	a		Section **AB** Any <u>two</u> from • Particles close together • Particle spacing increase with increasing time or increasing temperature • Particles in a fixed structure/(regular) lattice • Particles vibrate/perform SHM • Particles vibrate with increasing amplitude (from A to B) Section **CD** Any <u>two</u> from • Particles close together /(slightly) further apart (than in AB) • No regular structure /AW • Particles (are free to) move around / move past each other / flow • Particles move with increasing speed from C to D / greater KE	B1 x 2 B1 x 2	**Not**: 'vibrates more'
	b		$E = mc\Delta\theta$ (any subject) <u>and</u> gradient is larger for CD The specific heat capacity of the liquid is less than that of the solid.	M1 A1	**ORA** **Allow**: $\Delta\theta$ is larger for liquid in the same time interval or same energy supplied for "gradient" **Allow** $c \propto \text{gradient}^{-1}$ **Not:** c = 1 / gradient <u>**Examiner's Comments**</u> Many candidates realised that the gradients of the lines AB and CD were related to the specific heat capacities of the solid and liquid states. Higher level responses included the formula relating energy change, mass, specific heat capacity and the temperature change, and how that formula related to the gradient of the line on a temperature-time graph. Once that link was established, the lower gradient indicates a larger specific heat capacity.

Question			Answer/Indicative content	Marks	Guidance
	c		The sum of the (random) kinetic and potential energy of atoms or molecules in a substance	B1	**Allow** 'particles' Examiner's Comments This is a simple definition that many candidates recalled well. Lower level responses missed out that this is to do with the kinetic energy and potential energy of **particles**.
	d	i	$\frac{1}{2} m c_{RMS}^2 = 3/2\ kT$ $c_{RMS}^2 = 3 \times 1.38 \times 10^{-23} \times 523 / 4.8 \times 10^{-26}$ (Any subject) root mean square speed = 670 (m s^{-1})	C1 C1 A1	**Allow** this mark even when T = 250 is used subsequently **Not** 250°C **Allow** $c^2 = 4.5 \times 10^5$ **Allow** 2 marks for 4.5×10^5; mean square speed calculated **Allow** 1 mark for 464; no conversion to kelvin Examiner's Comments The key to this question is equating 2 formulae. The first is the familiar ½ m v^2 for kinetic energy. In this case, the squared speed will be the mean squared speed of the particles. The second is the connection between average kinetic energy of a particle at absolute temperature, T, $E_k = 3/2\ k\ T$. If candidates did that, then they not only scored the first mark but also could go on to complete the question. A common error was to forget to find the square root, as the question asks for the root mean square speed.

Question			Answer/Indicative content	Marks	Guidance
		ii	(number of molecules =) $1.3 \times 6.02 \times 10^{23}$ or 7.83×10^{23} mean KE = $\frac{3}{2} \times 1.38 \times 10^{-23} \times 523$ or 1.08×10^{-20} total kinetic energy = 8.5×10^{3} (J)	C1 C1 A1	**Not** 250°C **Allow** 8.4×10^{3} for use of 670 m s^{-1} **Allow** full credit for use of total KE = 1.5n*RT* **Allow** full credit for use of E_k for one molecule = ½ m c_{RMS}^2 (which may include ECF for their c_{RMS} in (d)(i)) **Allow** 2 marks for 4.0(5...) x 10^{3} (J) ; no conversion to kelvin. <u>Examiner's Comments</u> There were 2 ways to answer this question. The first was to find the kinetic of one particle using the mean square speed and the second was to find the kinetic energy of one particle using the absolute temperature. Lower level responses stopped at that point, or there was misunderstanding how to scale that value up to the whole gas. For either route, the value for one particle needed to be multiplied by the number of particles in the gas. This can be found by multiplying the number of moles by the Avagadro constant given in the data, formulae and relationship booklet.
			Total	13	
38			A	1	
			Total	1	

Question			Answer/Indicative content	Marks	Guidance
39	a	i	Any **THREE** from: Atoms of metal vibrate (about fixed points) Water molecules have translational KE The motion of the water molecules is random Metal atoms and water molecules have the same KE	B1×3	**Allow** particles for atoms / molecules throughout **Allow** idea that water particles move past each other **Not** idea that the water molecules have more KE than metal atoms
		ii	(E_{heater} =) 200 × 10 × 60 **or** 120000 (J) (E_{water} =) 0.5 × 4200 × 40 **or** 84000 (J) (energy transferred = 120000 – 84000) energy transferred = 3.6 ×10^4 (J)	C1 C1 A1	

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Marks</th><th>Guidance</th></tr>
<tr><td></td><td>b</td><td></td><td>Level 3 (5–6 marks)
Clear description and explanation and correct calculations leading to value of L_f

There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.

Level 2 (3–4 marks)
Clear description and explanation
or
Correct calculations leading to value of L_f
or
Some description or explanation and some correct calculations

There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.

Level 1 (1–2 marks)
Limited description or explanation
or
Limited calculations

The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.

0 marks
No response or no response worthy of credit.</td><td>B1×6</td><td>Indicative scientific points may include:

Description and explanation

• $m \propto t$ (for both)
• Greater gradient for funnel with heater / greater rate of water from funnel with heater
• Energy supplied to the ice is at a constant rate (for both beakers)
• Idea that arrangement in Fig 17.2 is a control
• Beaker in 17.2 heated just by surroundings / air / room
• Arrangement in Fig. 17.1 gains energy from heater and surroundings / air / room

Calculation

• Gradient(s) calculated
• $\Delta m = 45 \times 10^{-3}$ kg
• $\Delta E = mL_{(f)}$
• $\Delta E = 5 \times 12 \times 240 = 14400$ J
• $L_{(f)} = 14400 / 45 \times 10^{-3} = 3.2 \times 10^5$
• Units: J kg^{-1}

Note : $L_{(f)}$ can be calculated using $L_{(f)} = VI \div |\Delta\text{gradient}|$</td></tr>
<tr><td></td><td></td><td></td><td>Total</td><td>12</td><td></td></tr>
</table>

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
40	a	i	($pV = nRT$) $100 \times 10^3 \times (0.46)^3 = n \times 8.31 \times (273 + 20)$ $n = 4.0$	C1 A1	**Note** $T = 20$ is XP **Not** 1 SF answer of 4 **Note** answer is 4.00 to 3SF
		ii	$\frac{100}{293} = \frac{p}{1573}$ or $p \times (0.46)^3 = n \times 8.31 \times 1573$ pressure = 540 (kPa)	C1 A1	**Note** $T = 1300$ is XP **Allow** use of correct, unrounded n
	b	i	(p =) $6.6 \times 10^{-26} \times 990$ **or** $6.5(3) \times 10^{-23}$ (kg m s^{-1}) (Δp =) $2 \times 6.6 \times 10^{-26} \times 990$ $\Delta p = 1.3 \times 10^{-22}$ (kg m s^{-1})	C1 A1	 **Ignore** sign of answer
		ii	990/[2 × 0.46] (= 1080) ($F = \Delta p/\Delta t$) (F =) $1.3 \times 10^{-22} \times 1000$ $F = 1.3 \times 10^{-19}$ N	B1 C1 A1	 Possible ECF from **(b)(i)** **Note** 1080 would give 1.4×10^{-19} (N)
		iii	Use of $p = F/A$ **or** pressure = (total) force / area Idea of multiplying by total number of atoms	B1 B1	 **Allow** particles or molecules for atoms
			Total	**11**	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
41	a		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	**Allow** astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut) Examiner's Comments Misconception Experiencing weightlessness is not the same as being in freefall There was a lack of understanding of the nature of feeling weightless. The sensation of 'weightlessness' is a lack of the physiological sensation of 'weight'. The skeletal and muscular systems are no longer in a state of stress. This sensation is caused by a lack of contact forces as a result of the ISS and the astronaut experiencing the same acceleration. Common incorrect responses included: • the astronaut is weightless because he is falling • there is no resultant force on the astronaut • gravity is too weak to have any effect on the astronaut • the ISS orbits in a vacuum where there is no gravity.

Question			Answer/Indicative content	Marks	Guidance
	b	i	$M = 5.97 \times 10^{24}$(kg) **or** ISS orbital radius $R = 6.78 \times 10^6$(m) **or** $g \propto 1/r^2$ (gr^2 = constant so) $g \times (6.78 \times 10^6)^2 = 9.81 \times (6.37 \times 10^6)^2$ $g = 8.66$ (N kg^{-1})	C1 C1 A1	**or** g (= GM/R^2) = $6.67 \times 10^{-11} \times 5.97 \times 10^{24} / (6.78 \times 10^6)^2$ **Allow** rounding of final answer to 2 SF i.e. 8.7 (N kg^{-1}) <u>Examiner's Comments</u> The simplest method here was to use the fact that g is inversely proportional to r^2, so gr^2 = constant. If this was not used, a value for the mass of the Sun had to be calculated, which introduced a further step. Candidates who omitted this calculation and used a memorised value of the Sun's mass instead were unable to gain full marks, because they invariably knew it to 1 s.f. only, whereas 3 were required. Errors occurred when candidates used the incorrect distance in the formula for g. Common errors included: • forgetting to square the radius • using the Earth's radius rather than the orbital radius of the satellite • calculating $(6.37 \times 10^6 + 4.1 \times 10^5)$ incorrectly.
		ii	$2\pi r / T = v$ **or** $T = 2 \times 3.14 \times 6.78 \times 10^6 / 7.7 \times 10^3$ $T = 5.5 \times 10^3$ s (= 92 min)	M1 A1	**ECF** incorrect value of R from **b(i)**

Question			Answer/Indicative content	Marks	Guidance
	c		$\frac{1}{2}Mc^2$ ($\frac{1}{2}N_Amc^2$) $=\frac{3}{2}RT$ = $c^2 = 3 \times 8.31 \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ $\sqrt{c^2} = 500$ (m s^{-1}) (= 7.7×10^3 / 15)	C1 C1 A1 A0	or $\frac{1}{2}mc^2 = \frac{3}{2}kT$ or $c^2 = 3kT/m$ or $c^2 = 3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 293/2.9 \times 10^{-2} = 2.52 \times 10^5$ **not** (7.7×10^3 / 15) = 510 (m s^{-1}) **Examiner's Comments** The success in this question depended on understanding the meaning of the term *m* in the formula $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ given in the Data, Formulae and Relationship booklet. A significant number of candidates took *m* to be the mass of one mole (the molar mass, *M*) whereas *m* is actually the mass of one molecule. Candidates who used the formula $\frac{1}{2}M\overline{c^2} = \frac{3}{2}RT$ were usually more successful because the molar mass had been given in the question stem.
	d		power reaching cells (= *IA*) = $1.4 \times 10^3 \times 2500 = 3.5 \times 10^6$ W power absorbed = $0.07 \times 3.5 \times 10^6 = 2.45 \times 10^5$ W cells in Sun for (92 – 35 =) 57 minutes average power = $57/92 \times 2.45 \times 10^5 = 1.5 \times 10^5$ (W)	C1 C1 C1 A1	mark given for multiplication by 0.07 at any stage of calculation (90 – 35 =) 55 minutes using *T* = 90 minutes **ECF** value of *T* from **b(ii)** $55/90 \times 2.45 \times 10^5 = 1.5 \times 10^5$ (W) using *T* = 90 minutes **Examiner's Comments** Although this question looked daunting, it was actually quite linear and many candidates who attempted it were able to gain two or three marks even if they did not eventually get to the correct response. Candidates who set out their reasoning and working clearly were more liable to gain these compensatory marks.
			Total	13	

Question			Answer/Indicative content	Marks	Guidance
42			**Level 3 (5 – 6 marks)** Clear expansion of three statements *There is a well-developed line of reasoning which is clear and logically structured. The information presented is clear, relevant and substantiated.* **Level 2 (3 – 4 marks)** Clear expansion of two statements **or** Limited attempt at all three *There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.* **Level 1 (1 – 2 marks)** Limited attempt at one or two statements *There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.* **0 marks** *No response or no response worthy of credit.*	B1 x 6	**Use level of response annotations in RM Assessor,** **e.g. L2 for 4 marks, L2^ for 3 marks, etc.** **Indicative scientific points may include:** **statement 1** • fusion reactions are occurring • which change H into He • and mass is lost which releases energy • energy released = $c^2\Delta m$ • Δm per second = luminosity / c^2 **statement 2** • average k.e. of each proton is $\frac{3}{2}kT$ • high T means protons are travelling at high speed • so fast enough to overcome repulsive forces • and get close enough to fuse • p.e. = $e^2/4\pi\varepsilon_0 r$ so T must be high enough for $\frac{3}{2}kT > e^2/4\pi\varepsilon_0 r$ • r is approximately 3fm **statement 3** • k.e. ∝ T so average energy at 10^7 K is only one thousandth of the average energy at 10^{10} K when protons might fuse • but M-B distribution applies so at the high energy end there will be a few p with enough energy • quantum tunnelling across potential barrier is possible • small probability of many favourable collisions to boost energy of p • 4 p must fuse to produce He; it is complicated process making probability of fusion much less • number of p in Sun is so huge that, even with such a small probability, 4 x 10^9 kg of p still interact s^{-1} • a larger probability means lifetime of the Sun would be shorter

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
					<u>Examiner's Comments</u> This was one of the two LoR questions. It required understanding of fusion, mass-energy equivalence, the Maxwell-Boltzmann distribution, and the relationship between mean kinetic energy and temperature for particles in an ideal gas. Responses to the following questions were being sought: 1. Why is the Sun losing mass? 2. Why is an extremely high temperature needed for fusion in stars? 3. Why does fusion occur in the Sun even though its temperature is 1,000 times less than that required by theory? Two dissimilar responses could score comparable marks if the criteria set out in the answer section of the marking scheme were met. Level 3 responses gave a clear answer to all three of the questions, whereas Level 2 responses generally had clear answers to only two. In Level 1, limited answers to only one or two of the above questions were given.
			Total	6	