Thermal Physics

1. 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]**

2. 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]**

3. Define *specific heat capacity* of a substance.

--- **[1]**

4. Define the *internal energy* of a substance.

--- **[1]**

5 (a). A meteorological balloon rises through the atmosphere until it expands to a volume of 1.0×10^6 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 1.3×10^4 m^3.

[3]

(b). 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]**

(c). 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]**

(d). 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]**

6. State what is meant by the **internal energy** of a substance.

---

[1]

7. A piston has a fixed amount of trapped ideal gas.

The gas exerts pressure *p* and has volume *V*. The thermodynamic (absolute) temperature of the gas is *T*. The mass of each atom is *m*. There are *N* atoms of the gas. The Boltzmann constant is *k*.

What quantities are required to determine the root mean square speed $\sqrt{\overline{c^2}}$ of the atoms?

A *k* and *T*
B *p* and *V*
C *p*, *V* and *T*
D *p*, *V*, N and *m*

Your answer ☐ **[1]**

8. 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]**

9. 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]

10. The freezing point of ethanol is 159 K.
What is 159 K in °C?

A – 432 °C
B – 114 °C
C 114 °C
D 432 °C

Your answer **[1]**

11. 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]**

12. 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]**

13. 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]**

14. 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]**

15. 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}.

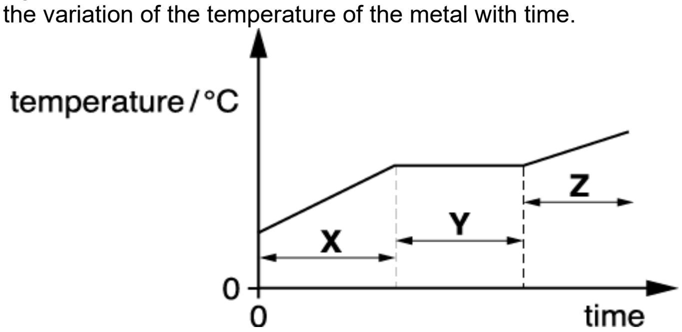
Over a period of time, a third of the gas molecules escape from the container. The pressure and volume of the gas in the container remain the same.

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]**

16. 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]**

17. 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]

18. 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]

19. 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.

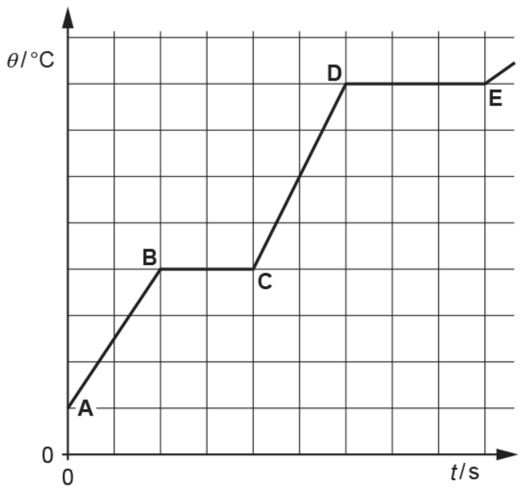


Fig. 21

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

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[2]

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

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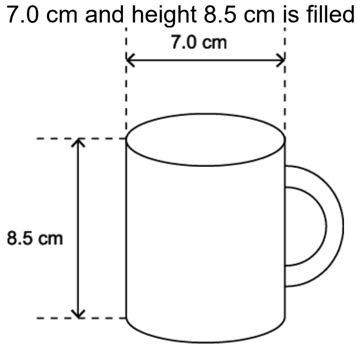
[2]

21. 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]**

22. 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.

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[2]

23. 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

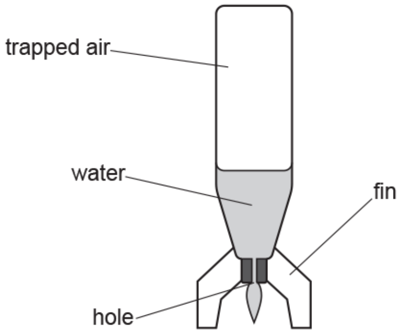

Fig. 2.1

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

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

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

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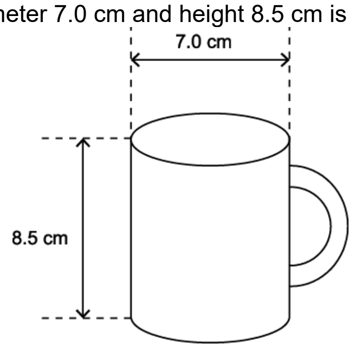
[3]

25 (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}.

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]

(b). 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.

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[3]

26 (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.

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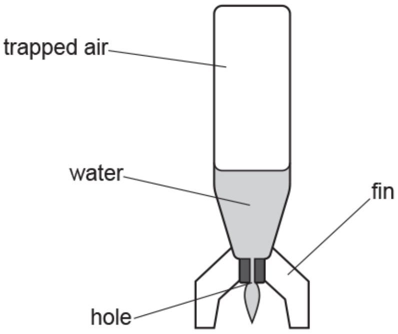


Fig. 2.1

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]**

(b). 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]**

27 (a). 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.

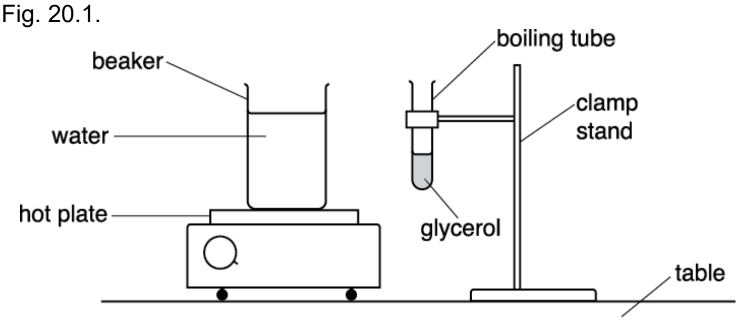


Fig. 20.1

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]

(b). 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.

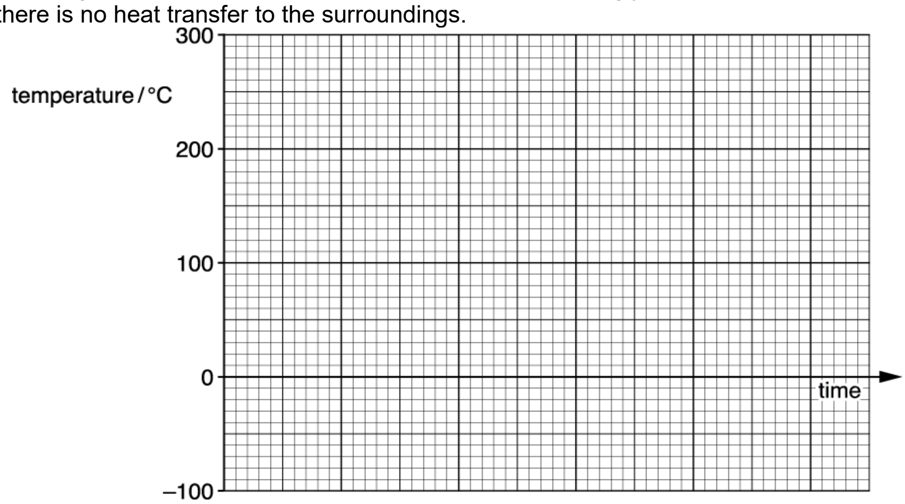


Fig. 20.2

[3]

28 (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]**

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

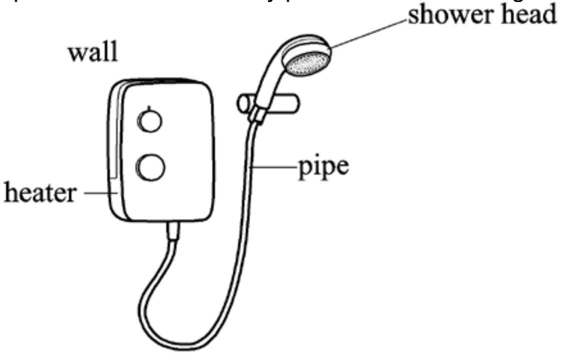


Fig.1.1

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]**

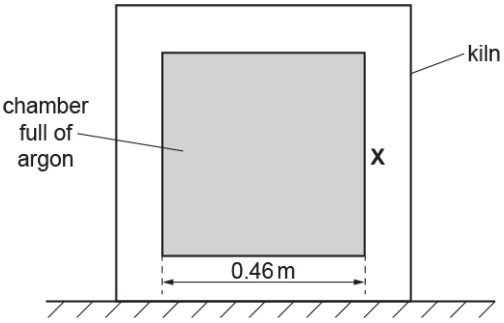
30. A plastic kettle is filled with 0.60 kg of water at a temperature of 20°C.
A 2.2 kW electric heater is used to heat the water for a time of 4.0 minutes.

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]**

31. 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]**

32. 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]

33. 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.

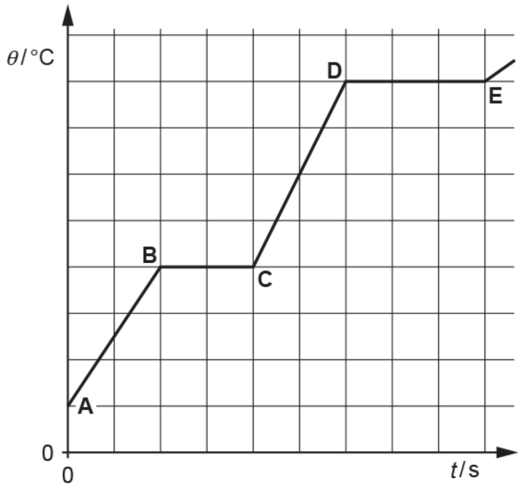


Fig. 21

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]

34 (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.

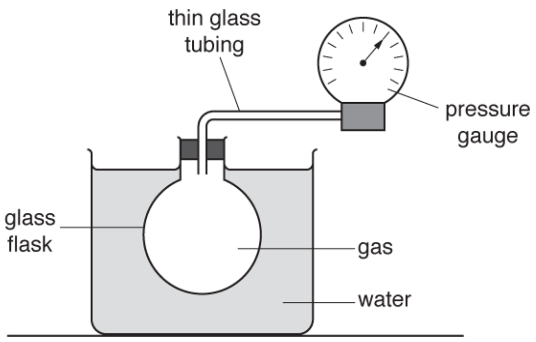


Fig. 17.1

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.

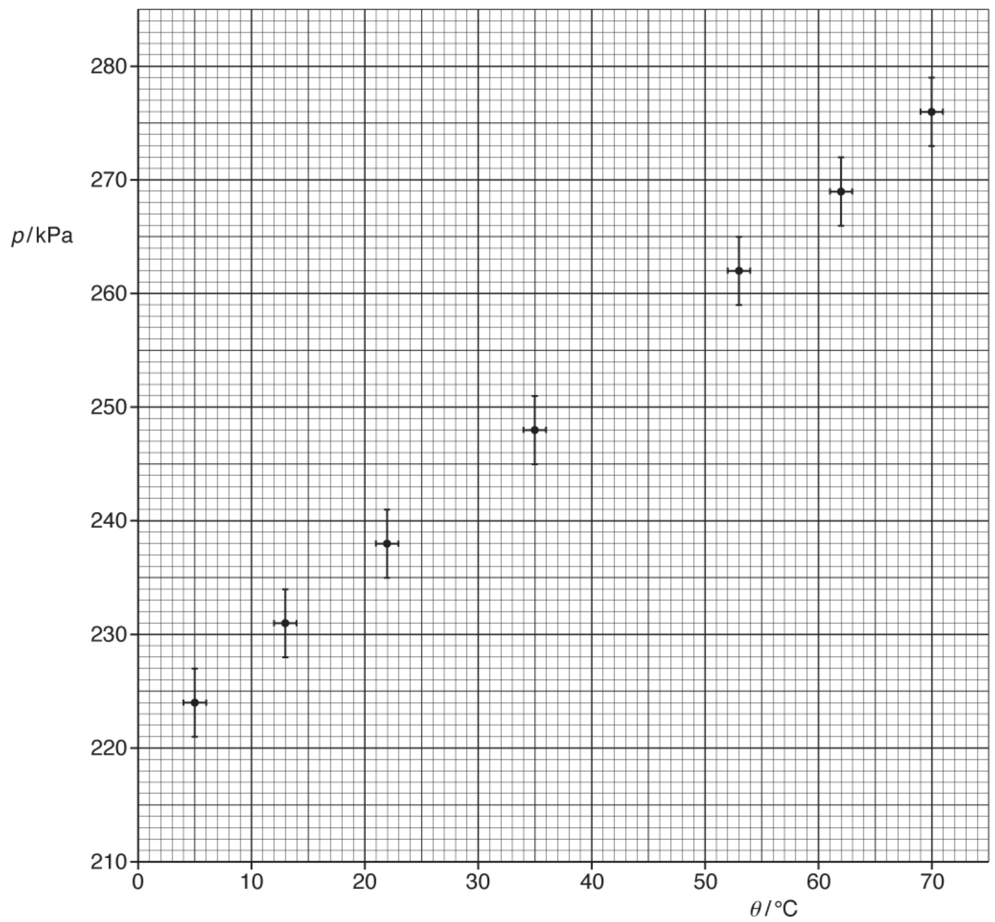


Fig. 17.3

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]

35. 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]

36. Some nuclear fission reactors use uranium-235 as fuel. In the future, there is possibility of using hydrogen-2 as fuel in fusion reactors.

Here is some information and data on fission and fusion reactions.

	Fission reactor	**Fusion reactor**
Typical reaction	${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{89}_{36}Kr + 3{}^{1}_{0}n$	${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}H + {}^{1}_{1}H$
Approximate energy produced in each reaction	200 MeV	4 MeV
Molar mass of fuel material	uranium-235: 0.235 kg mol^{-1}	hydrogen-2: 0.002 kg mol^{-1}

- Describe the similarities and the differences between fission and fusion reactions.
- Explain with the help of calculations, which fuel produces more energy per kilogram.

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[6]

37. This question is about an electric cooker, which consists of an oven and an electromagnetic induction hob.

The oven is not sealed, so the air inside remains at atmospheric pressure of 1.0×10^5 Pa.
The volume of the oven is 0.065 m3. The air inside the oven behaves as an ideal gas.

The temperature of the oven increases from room temperature to 200 °C.

Show that the internal energy of the air in the oven is the same at all temperatures of the oven.
Support your answer with an explanation of the motion of the air molecules in terms of kinetic theory. **[6]**

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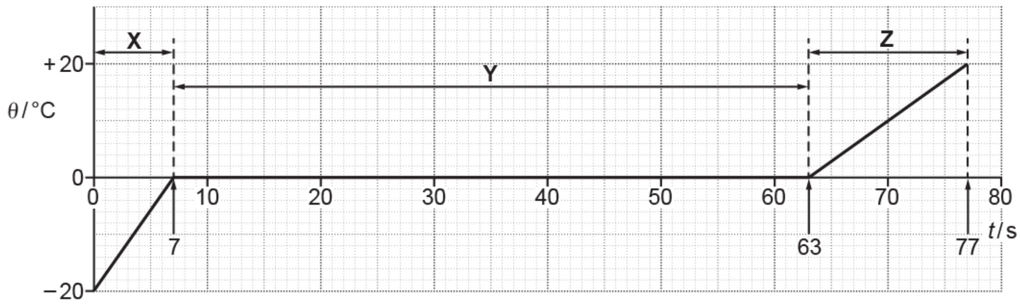
38. A 150 W heater is used to heat 25 g of ice in a sealed and well-insulated container. The initial temperature of the ice is – 20 °C. The graph shows the variation of temperature θ with time t as the ice is heated.



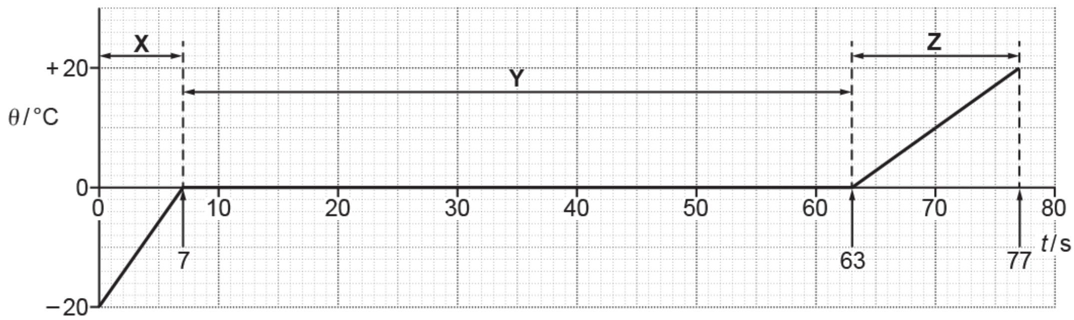
There are three distinct regions of the graph, **X**, **Y** and **Z**.

i. Describe the motions of the molecules in region **X** and in region **Z**.

[2]

ii. The internal energy of the ice increases from t = 0 to t = 77 s.
Complete the table below using the following key for the physical quantities:

- K = kinetic energy of molecules
- P = potential energy of molecules.



Region	**Physical quantity, or quantities, that increases as time increases**	**Physical quantity, or quantities, that remain constant as time increases**
X		
Y		
Z		

[3]

iii. State the temperature of the ice at which its molecules have zero kinetic energy.

---

[1]

39. 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.

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[6]

40 (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*.

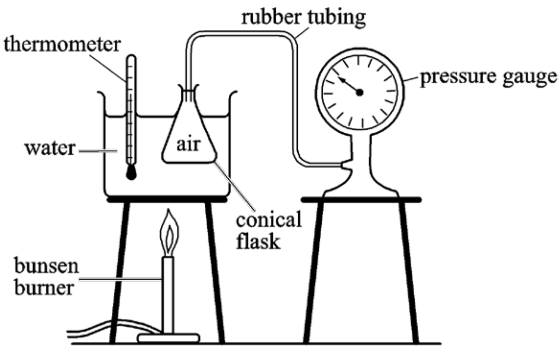


Fig. 20.1

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**.

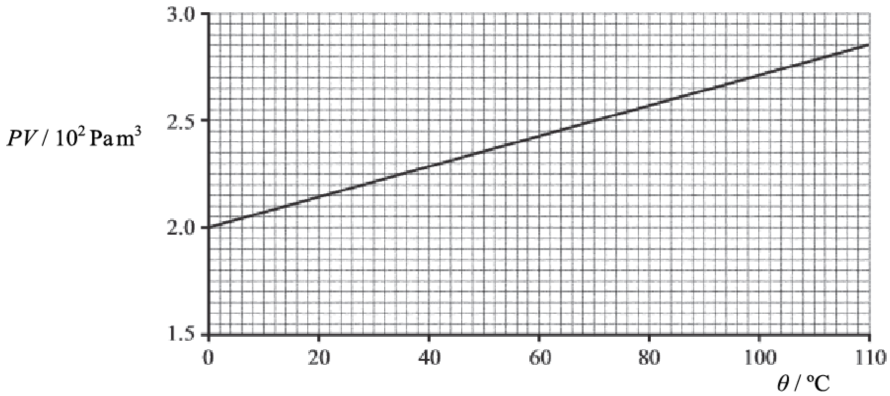


Fig. 20.2

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]**

41. A 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 ºC.

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

ii. Calculate the internal energy of 1.3 moles of the gas at 250 ºC.

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

42. 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.

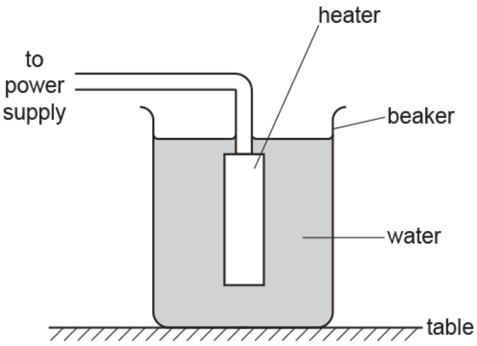
v = ... m s^{-1} **[1]**

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

----

[3]

43 (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**.

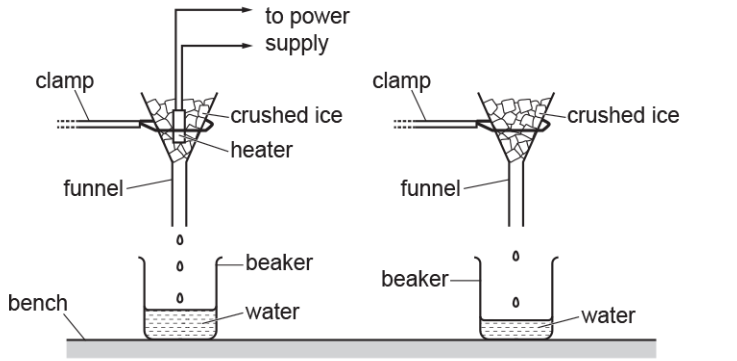


Fig. 17.1 **Fig. 17.2**

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.

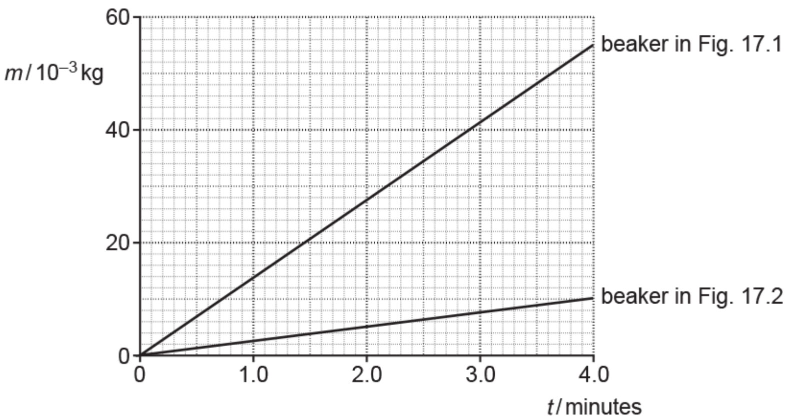


Fig. 17.3

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]

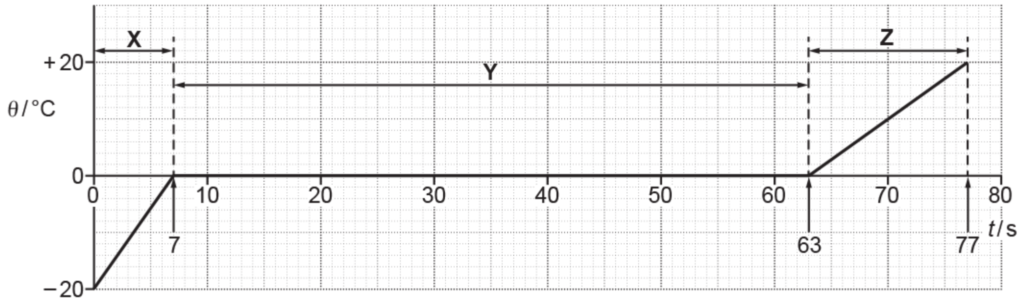
44. There is a lot of helium in the Universe. This was also true of the Earth when it was formed billions of years ago. However, only small traces of helium are now found in the atmosphere of the Earth.

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]

45. A 150 W heater is used to heat 25 g of ice in a sealed and well-insulated container. The initial temperature of the ice is – 20 °C. The graph shows the variation of temperature *θ* with time *t* as the ice is heated.



There are three distinct regions of the graph, **X**, **Y** and **Z**.

i. Use the graph to determine the specific heat capacity *c* of the ice.

c = ... J kg^{-1} K^{-1} **[3]**

ii. Use the graph to determine the specific latent heat of fusion of ice L_f.

L_f = ... J kg^{-1} **[2]**

iii. Use the graph to compare the specific heat capacities of ice and water. Explain your answer.

---

[2]

46. 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}.

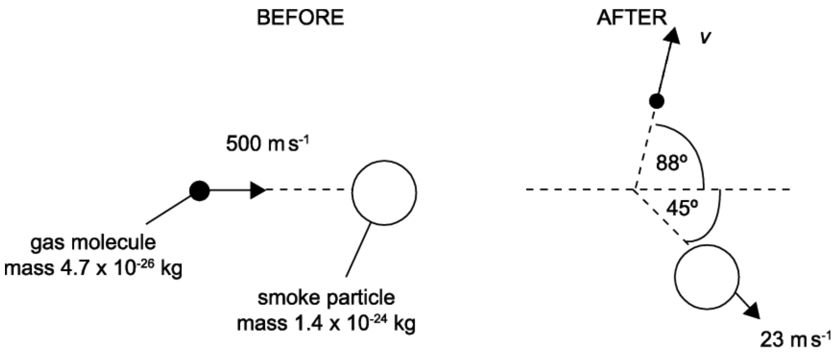


Fig. 20

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.

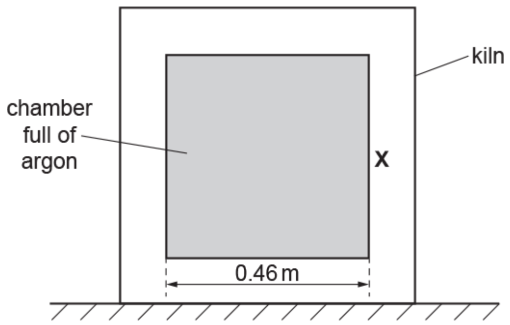
---

[2]

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

v = ...m s^{-1} **[2]**

47. 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 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 Δ*p* of this atom.
   - mass of argon atom = 6.6×10^{-26} kg

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

[1]

   - 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]

48. 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**.

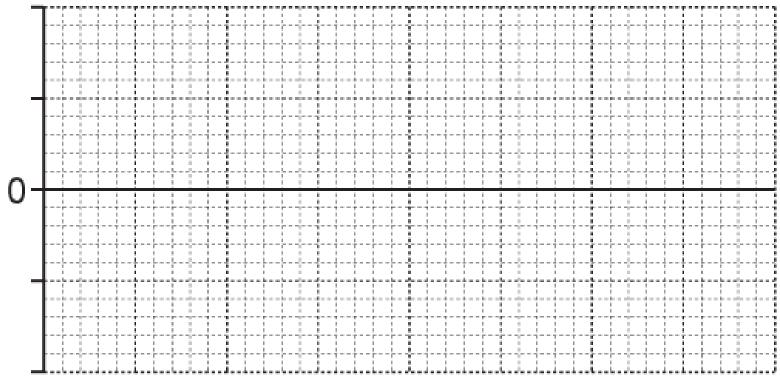


Fig. 5.2

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]**

49. 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.

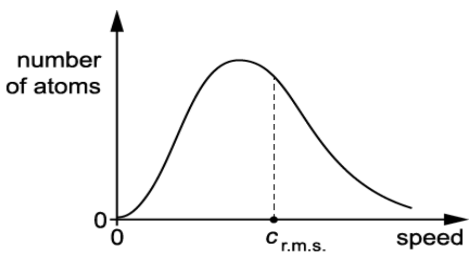


Fig. 1

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.

----

[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]

END OF QUESTION PAPER