

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]

5.1 Thermal Physics

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

The pressure of the atmosphere at the Earth's surface = $1.0 \times 10^5 \text{ Pa}$.

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

$$PV = nRT \rightarrow \frac{PV}{T} = nR$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$V_1 = \frac{P_2 V_2 \times T_1}{T_2 P_1}$$

$$T_1 = 17^\circ \text{C} = 290^\circ \text{K} \quad V_1 = ? \quad P_1 = 1 \times 10^5 \text{ Pa}$$

$$T_2 = -43^\circ \text{C} = 230^\circ \text{K} \quad V_2 = 1 \times 10^6 \text{ m}^3 \quad P_2 = 1 \times 10^3 \text{ Pa}$$

$$V_1 = \frac{1 \times 10^3 \times 1 \times 10^6 \times 290}{230 \times 1 \times 10^5} = 12608 \approx 1.3 \times 10^4 \text{ m}^3$$

[3]

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

Calculate

$$PV = nRT \rightarrow n = \frac{PV}{RT} = \frac{1 \times 10^5 \times 12608}{8.31 \times (17 + 273)} = 523175 \text{ moles}$$

i. the number of moles of gas in the balloon

number of moles = [2]

ii. the mass of gas in the balloon.

$$523175 \times 4 \times 10^{-3} = 2092 \text{ kg}$$

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 .

$$E \propto T \quad 1900 \times \frac{-43 + 273}{17 + 273} = 1506.9 \text{ MJ}$$

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.

U : upthrust $V = 12608 \text{ m}^3$

$U = \text{weight of air displaced} = \rho V g = 1.3 \times 12608 \times 9.81 = 160789.8 \text{ N}$

$M = \dots \text{ kg}$ [3]



$$F = ma \rightarrow$$

$$F = U - W = U - mg = ma \rightarrow U = (g + a)m \rightarrow m = \frac{U}{g + a} = \frac{160789.8}{9.81 + 27} =$$

5.1 Thermal Physics

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 $\sqrt{c^2}$ of the atoms?

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

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

$$pV = nRT$$

$$pV = NkT$$

$$k = \frac{R}{N_A} \checkmark = 6.02 \times 10^{23}$$

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 $\text{J mol}^{-1} \text{K}^{-1}$?

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

$$pV = nRT$$

$$R = \frac{pV}{nT}$$

$$n=1 \rightarrow R = \frac{pV}{T} \rightarrow D$$

$$Pa = N/m^2 \quad J = N \cdot m$$

$$V = m^3$$

$$R = 8.31 \frac{J}{mol \cdot K}$$

Your answer

☐

[1]

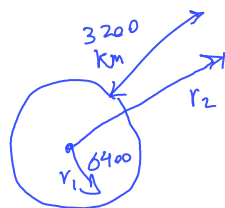
9. A satellite is in a circular orbit around the Earth. The vertical **height** of the satellite above the surface of the Earth is 3200 km. The radius of the Earth is 6400 km. (Gravitational Fields!)

What is the ratio

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

$$F = G \frac{m_1 m_2}{r^2}$$

- A 0.25
- B 0.44
- C 0.50
- D 0.67



$$r_2 = 9600$$

$$r_1 = 6400$$

$$\frac{F_2}{F_1} = \frac{r_1^2}{r_2^2} = \frac{(6400)^2}{(9600)^2} = 0.44 \quad (B)$$

Your answer

☐

[1]

5.1 Thermal Physics

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

$$159 - 273 = -114^{\circ}\text{C}$$

Your answer

[1]

11. A gas syringe contains 2.0 moles of an ideal gas of volume of 0.040 m³.
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 m³
- B 0.032 m³
- C 0.050 m³
- D 0.090 m³

$$PV = nRT \rightarrow \frac{V}{n} = \frac{RT}{P}$$

$$\frac{V_1}{n_1} = \frac{V_2}{n_2} \rightarrow V_2 = \frac{V_1}{n_1} \times n_2 = \frac{0.04}{2} \times 2.5 = 0.05 \text{ m}^3$$

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

$$Q = mc \Delta T = 0.28 \times 130 \times (82 - 20) = 2256.8 \text{ J}$$

$$P = \frac{E}{t} = \frac{2256.8}{1.2 \times 60} = 31.34 \text{ W}$$

Your answer

[1]

13. What is the correct unit for specific heat capacity?

- A. m²s⁻²K⁻¹
- B. ms⁻²K⁻¹
- C. m²s⁻¹K⁻¹
- D. m²s⁻²K

$$Q = mc \Delta T \rightarrow c = \frac{Q}{m \Delta T} = \frac{E}{\text{kg K}} = \frac{\text{J}}{\text{kg K}} = \text{kg}^{-1} \text{K}^{-1}$$

Your answer

$$E = \text{work} = F \cdot d = (ma) \cdot d = (\text{kg m s}^{-2}) \text{ m}$$

[1]

$$\Rightarrow c = \frac{(\text{kg m s}^{-2}) \text{ m}}{\text{kg}^{-1} \text{K}^{-1}} = \text{m}^2 \text{s}^{-2} \text{K}^{-1}$$

5.1 Thermal Physics

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

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

- A $4.1 \times 10^4 \text{ J}$
- B $1.2 \times 10^6 \text{ J}$
- C $6.9 \times 10^7 \text{ J}$
- D $3.8 \times 10^9 \text{ J}$

$$\text{mass} = \text{molar mass} \times \text{No. of moles} \rightarrow m = 0.018 \times 30 = 0.54 \text{ kg}$$

$$E = mL = 0.54 \times 2300 \times 10^3 = 1242000 \text{ J} \approx 1.2 \times 10^6 \text{ J}$$

Your answer

[1]

15. A container has an ideal gas. The mean square speed of the gas molecules in the container is $3.0 \times 10^5 \text{ m}^2 \text{ s}^{-2}$.

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?

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

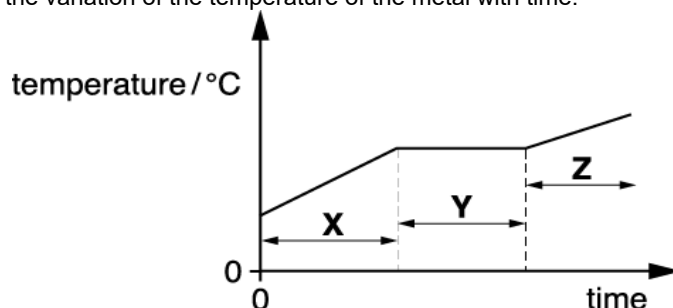
- A $1.0 \times 10^5 \text{ m}^2 \text{ s}^{-2}$
- B $2.0 \times 10^5 \text{ m}^2 \text{ s}^{-2}$
- C $4.5 \times 10^5 \text{ m}^2 \text{ s}^{-2}$
- D $9.0 \times 10^5 \text{ m}^2 \text{ s}^{-2}$

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 $2T$. The new pressure exerted by the gas is $3p$.

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. $6V$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \rightarrow V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{p V (2T)}{3p T}$$

$$V_2 = \frac{2}{3} V \rightarrow B$$

Your answer ☐

$$\begin{array}{ll} P_1 = p & P_2 = 3p \\ V_1 = V & V_2 = ? \\ T_1 = T & T_2 = 2T \end{array}$$

[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.

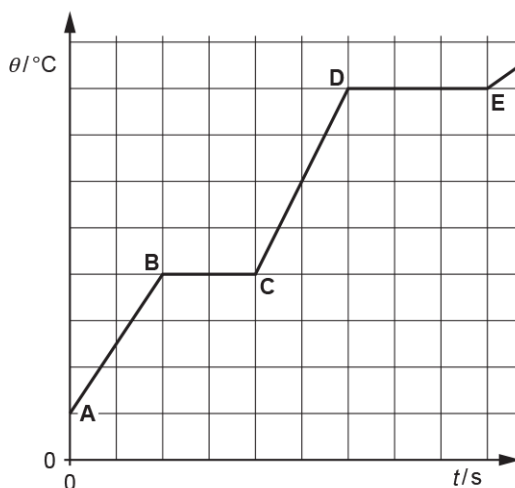


Fig. 21

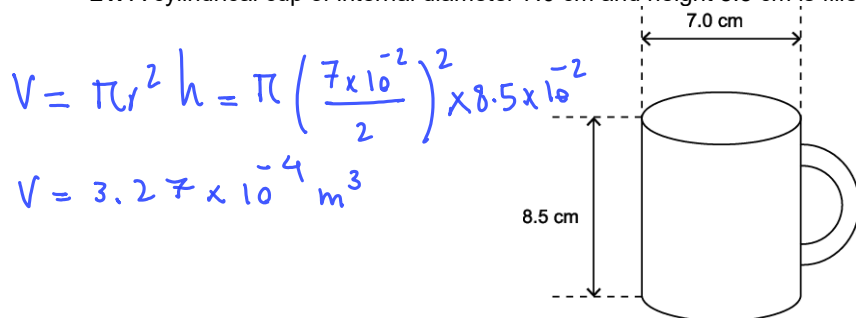
Use Fig. 21 to explain how the specific heat capacity of the liquid compares with the specific heat capacity of the solid.

[2]

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

[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 $4200 \text{ J kg}^{-1} \text{ K}^{-1}$.

Calculate the number of water molecules in the cup.

$$\rho = \frac{m}{V} \longrightarrow m = \rho V = 1000 \times 3.27 \times 10^{-4} = 0.327 \text{ kg} = 327.12 \text{ g}$$

$$\text{No. of moles: } \frac{327.12}{18} = 18.17$$

$$\text{No. of molecules} = \text{No. of moles} \times N_A$$

number of molecules = 1.09×10^{25} [2]

Avogadro's 6.02×10^{23}

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.

[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.

$$1 \text{ litre} = 10^{-3} \text{ m}^3$$

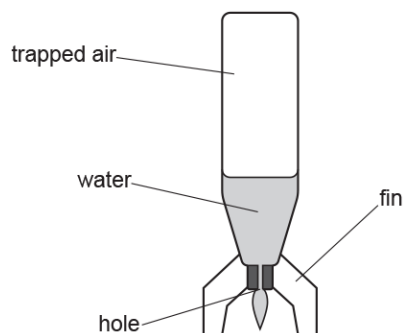


Fig. 2.1

$$V = 1.2 \text{ litre} = 1.2 \times 10^{-3} \text{ m}^3$$

$$T = 17 + 273 = 290 \text{ } ^\circ\text{K}$$

$$P = 2.4 \times 10^5 \text{ Pa}$$

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

$$PV = nRT \rightarrow n = \frac{PV}{RT} = \frac{2.4 \times 10^5 \times 1.2 \times 10^{-3}}{8.31 \times 290} = 0.119 \text{ moles}$$

→ Go to Q26!

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

24. Brownian motion provides evidence for a kinetic model of gases.

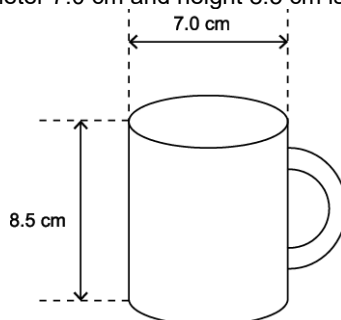
State **three** key assumptions made in the kinetic theory of gases .

[3]

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

Calculated in Q21

$$m = 0.327 \text{ kg}$$



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 $4200 \text{ J kg}^{-1} \text{ K}^{-1}$.

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.

$$P = \frac{E}{t} \quad E = mc\Delta T = 0.327 \times 4200 \times (100 - 20) = 109872 \text{ J}$$

$$t = \frac{E}{P} = \frac{109872}{0.5 \times 1000} = 219.74 \text{ s}$$

kilo-watt

[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.

[3]

5.1 Thermal Physics

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.

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

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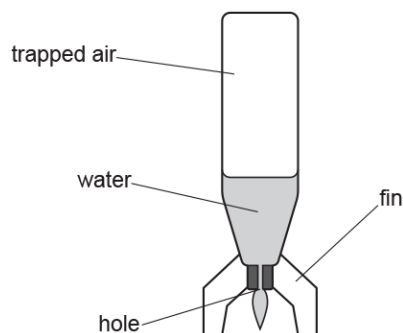


Fig. 2.1

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.

$$T \text{ Constant} \longrightarrow P_1 V_1 = P_2 V_2 \longrightarrow P_2 = \frac{P_1 V_1}{V_2} = \frac{2.4 \times 10^5 \times 1.2 \times 10^{-3}}{1.5 \times 10^{-3}} = 1.92 \times 10^5 \text{ Pa}$$

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 = $1.1 \times 10^{-4} \text{ m}^2$
 initial pressure of trapped air = 2.4×10^5 Pa
 atmospheric pressure = 1.0×10^5 Pa
 density of water = $1.0 \times 10^3 \text{ kg m}^{-3}$

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

$$p = \frac{F}{A} \longrightarrow F = pA = 1.4 \times 10^5 \times 1.1 \times 10^{-4} = 15.4 \text{ N} \longrightarrow \text{upward force}$$

atmospheric pressure

pressure of air as it comes out: $(2.4 - 1) \times 10^5 = 1.4 \times 10^5 \text{ Pa}$ [2]

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

$$a = \frac{F}{m} = \frac{11.9665}{0.3 + 0.05} = 34.19 \text{ m s}^{-2}$$

means water is still in the bottle!

mass of water:
 $m = \rho V = 1000 \times 0.3 \times 10^{-3} = 0.3 \text{ kg}$

Resultant force = upward force - weight =

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

$15.4 - (0.05 + 0.3) \times 9.81 = 11.9665 \text{ N}$

5.1 Thermal Physics

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.

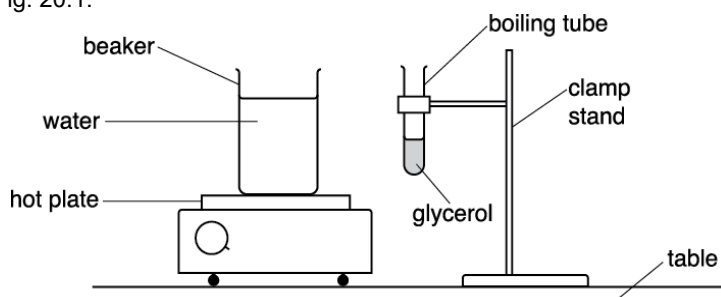


Fig. 20.1

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

	m / g	$c / \text{J kg}^{-1} \text{K}^{-1}$
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.

$$E = mc\Delta\theta = 0.15 \times 4200 \times 55 = 34650 \text{ J}$$

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 .

$$\begin{aligned} \Delta E_w &= \Delta E_g \\ m_w c_w (75 - \theta) &= m_g c_g (\theta - 20) \\ 0.15 \times 4200 (75 - \theta) &= 0.02 \times 2400 (\theta - 20) \rightarrow \\ 630(75 - \theta) &= 48(\theta - 20) \\ 13.125(75 - \theta) &= \theta - 20 \rightarrow \\ 984.375 - 13.125\theta &= \theta - 20 \\ 14.125\theta &= 1004.375 \rightarrow \theta = 71.1^\circ\text{C} \end{aligned}$$

$\theta = \dots\dots\dots^\circ\text{C}$ [3]

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

The temperature is less / different because of thermal energy of the water is also used to warm up the boiling tube.

[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 .

$$c_s < c_l$$

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).

- Calculate the value of the gravitational field strength g at the height of the ISS above the Earth.

$$g = \dots\dots\dots \text{ N kg}^{-1} \quad [3]$$

- 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]

5.1 Thermal Physics

(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 = $2.9 \times 10^{-2} \text{ kg mol}^{-1}$
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.

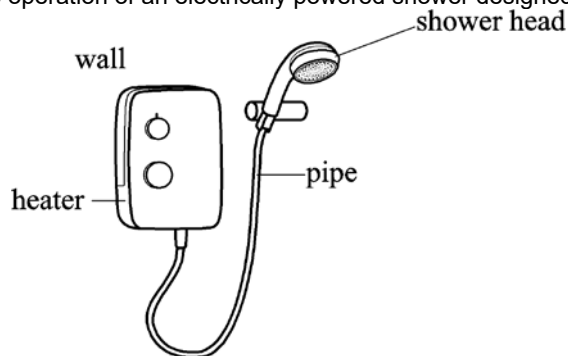


Fig.1.1

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 = $4200\text{ J kg}^{-1}\text{ K}^{-1}$

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

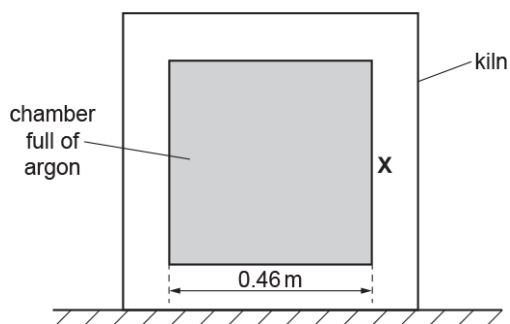
30. A plastic kettle is filled with 0.60 kg of water at a temperature of 20°C .
A 2.2 kW electric heater is used to heat the water for a time of 4.0 minutes.

The specific heat capacity of water is $4200\text{ J kg}^{-1}\text{ K}^{-1}$ and the specific latent heat of vaporisation of water is $2.3 \times 10^6\text{ J kg}^{-1}$. 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.

$n = \dots\dots\dots$ 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 = $\dots\dots\dots$ 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.

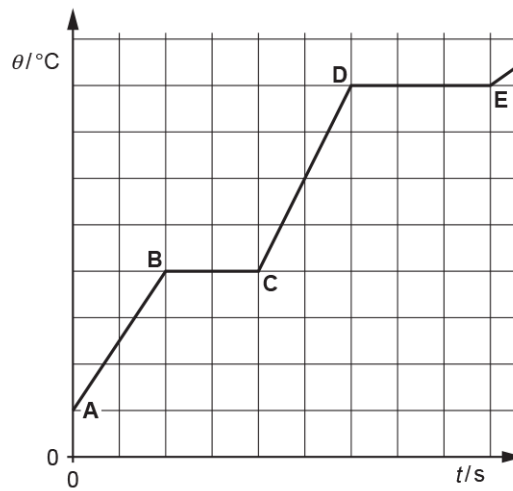


Fig. 21

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.

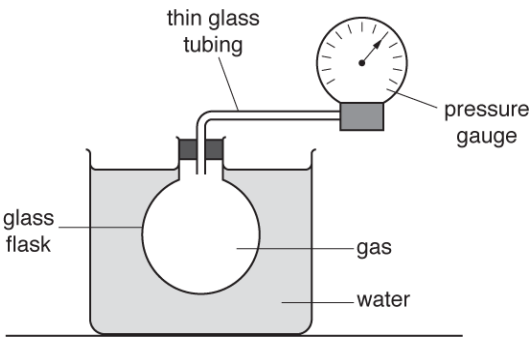


Fig. 17.1

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.

$\theta / ^\circ\text{C}$	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.

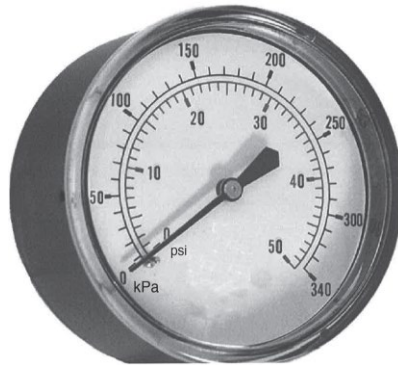


Fig. 17.2

- 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 $44 \pm 1^\circ\text{C}$. 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 .

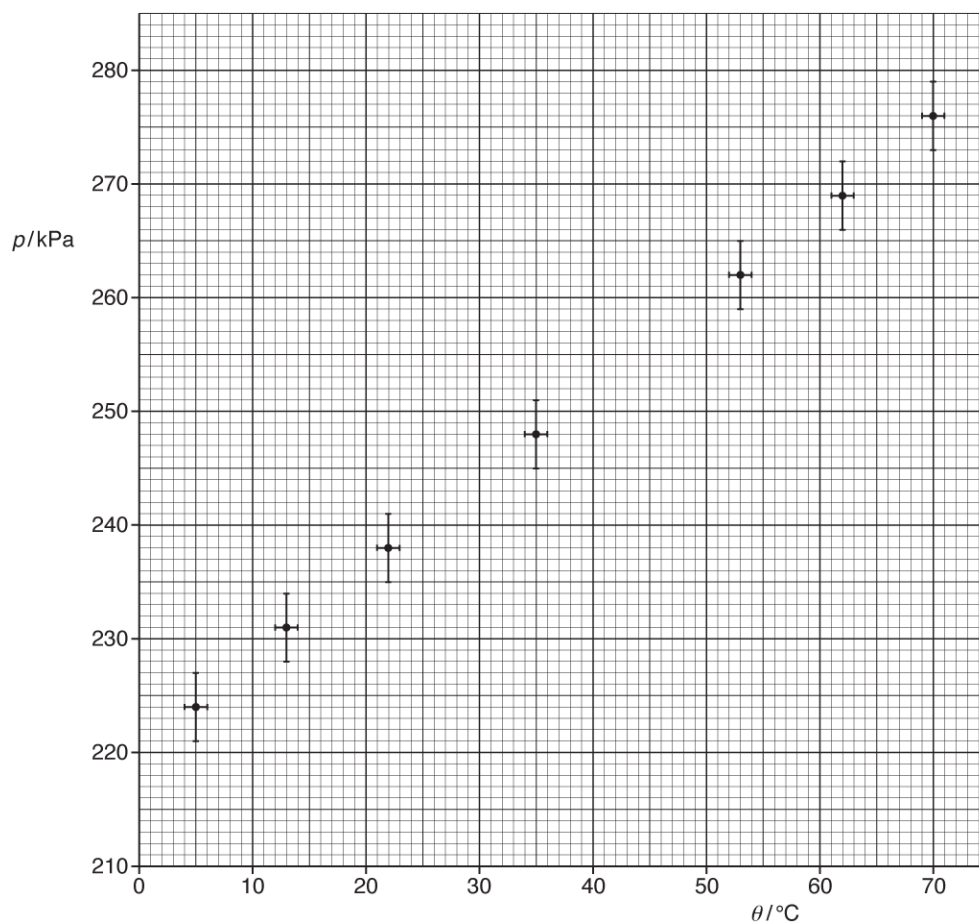


Fig. 17.3

- 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.

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5.1 Thermal Physics

(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]

5.1 Thermal Physics

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	${}_0^1\text{n} + {}_{92}^{235}\text{U} \rightarrow {}_{56}^{144}\text{Ba} + {}_{36}^{89}\text{Kr} + 3{}_0^1\text{n}$	${}_1^2\text{H} + {}_1^2\text{H} \rightarrow {}_1^3\text{H} + {}_1^1\text{H}$
Approximate energy produced in each reaction	200 MeV	4 MeV
Molar mass of fuel material	uranium-235: $0.235 \text{ kg mol}^{-1}$	hydrogen-2: $0.002 \text{ kg mol}^{-1}$

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

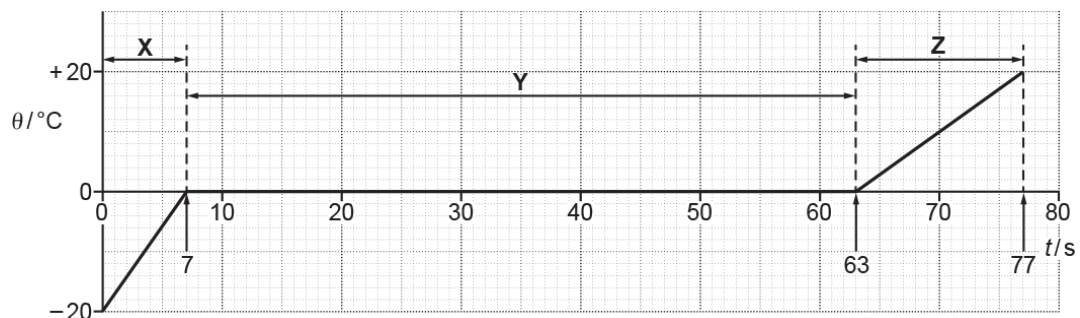
This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

[illegible]

The graph shows temperature $\theta/^\circ\text{C}$ on the vertical axis and time t/s on the horizontal axis. The vertical axis has markings at -20, 0, and +20. The horizontal axis has markings at 0, 10, 20, 30, 40, 50, 60, 70, and 80. The function is defined by three segments: a linear increase from -20 to 0 between $t=0$ and $t=7$; a constant value of 0 between $t=7$ and $t=63$; and a linear increase from 0 to +20 between $t=63$ and $t=77$. The areas under these segments are labeled X, Y, and Z respectively.

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

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



5.1 Thermal Physics

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.

This image shows a blank sheet of white paper with horizontal ruling lines. The lines are evenly spaced and extend across the width of the page. There are no margins, text, or other markings on the paper.

The diagram illustrates a laboratory setup for studying the relationship between temperature and gas pressure. A conical flask containing air is partially submerged in a beaker of water. A thermometer is placed in the water to monitor its temperature. The flask is sealed with a stopper, and a tube of rubber tubing connects it to a pressure gauge. The entire setup is supported by two stands. A Bunsen burner is positioned below the beaker to heat the water, which in turn heats the air in the flask. Labels with leader lines identify the thermometer, water, bunsen burner, conical flask, rubber tubing, and pressure gauge.

[illegible]

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5.1 Thermal Physics

(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**.

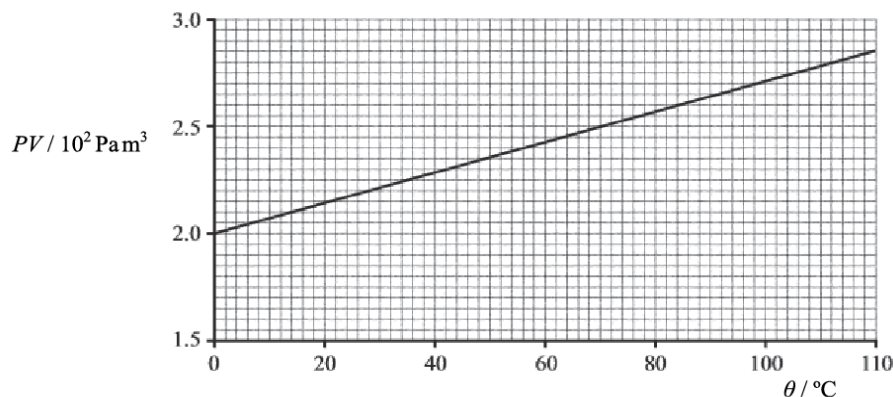


Fig. 20.2

- 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
- the mass of the gas

mass = kg

- 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°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]

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]

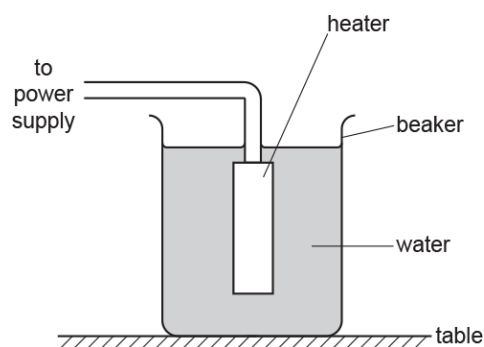
- i. Calculate the escape velocity v of gas molecules on the surface of Pluto.

$v = \dots\dots\dots \text{m s}^{-1}$ [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]**

5.1 Thermal Physics

(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**.

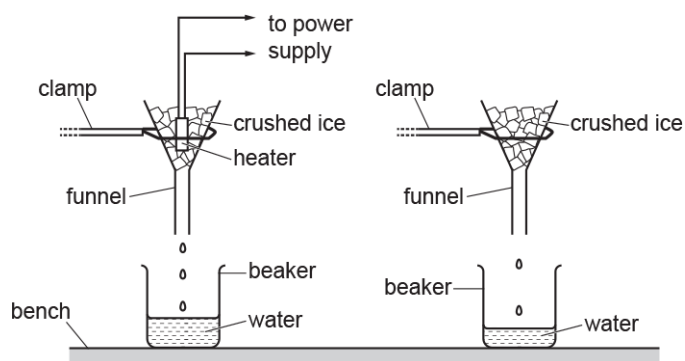


Fig. 17.1

Fig. 17.2

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

The current in the heater is 5.0 A 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 .

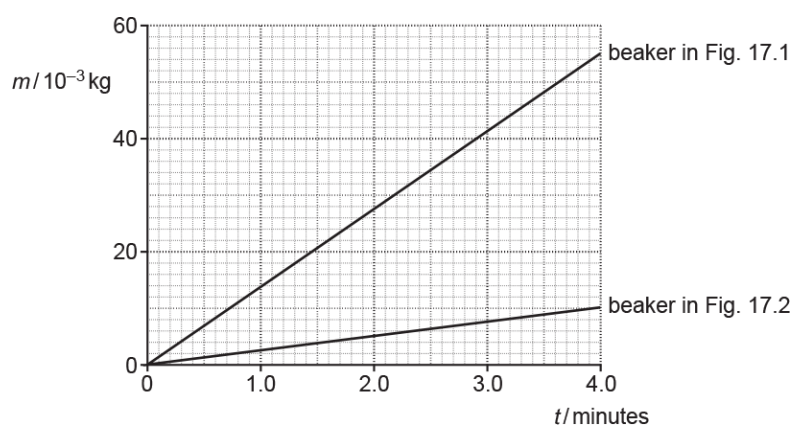


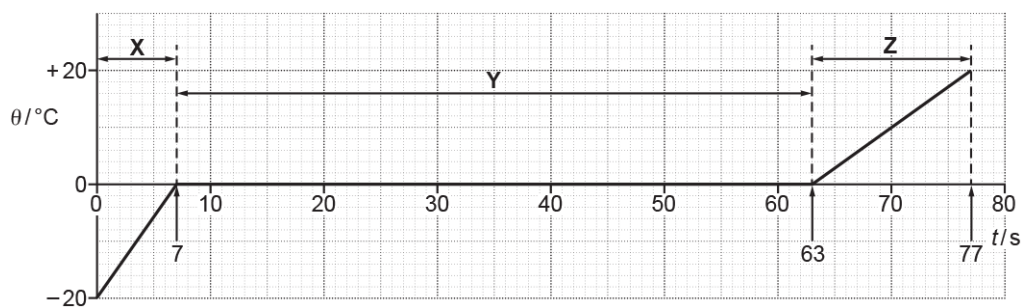
Fig. 17.3

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.

44. 

5.1 Thermal Physics

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 $-20\text{ }^{\circ}\text{C}$. 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.

$$c = \dots\dots\dots \text{J kg}^{-1} \text{K}^{-1} \text{ [3]}$$

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

$$L_f = \dots\dots\dots \text{J kg}^{-1} \text{ [2]}$$

- 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 $4.7 \times 10^{-26} \text{ kg}$.

- 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} .

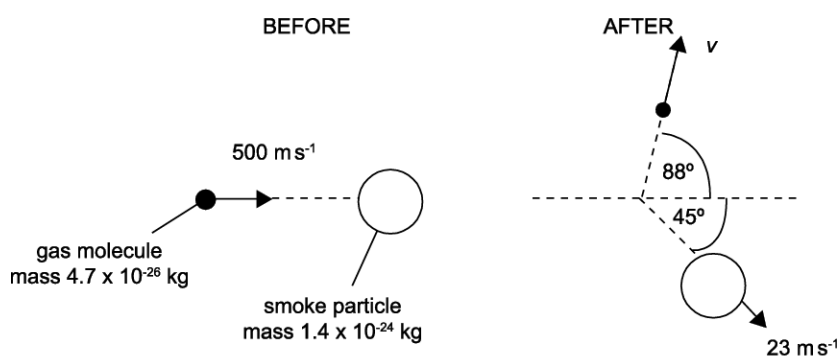


Fig. 20

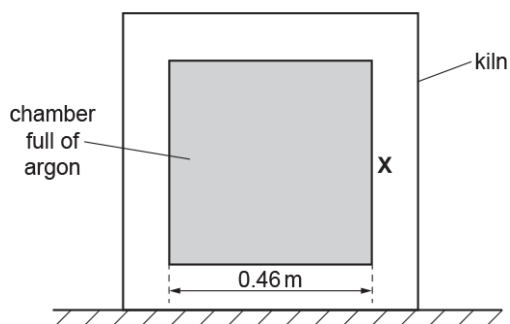
1. State and explain the **total** momentum of the molecule and smoke particle after the collision in a direction perpendicular to initial velocity of the gas molecule.

[2]

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

$v = \dots\dots\dots \text{m s}^{-1}$ [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 Δp of this atom.
 - mass of argon atom = 6.6×10^{-26} kg

$$\Delta p = \dots\dots\dots \text{ kg m s}^{-1} \text{ [2]}$$

- 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.

$$F = \dots\dots\dots \text{ N [2]}$$

- 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**.

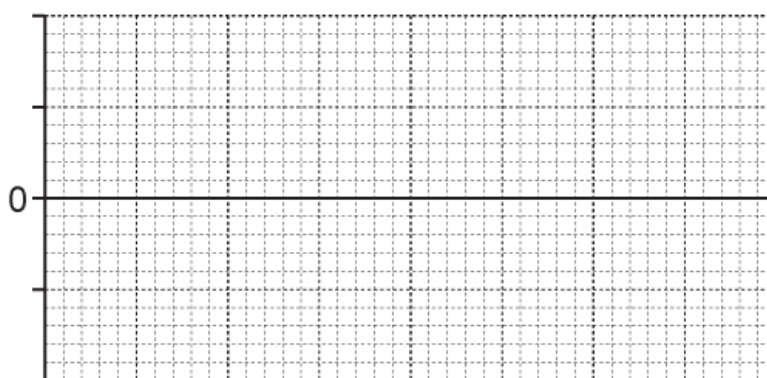


Fig. 5.2

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

$$v_{\text{max}} = \dots \text{ m s}^{-1} \quad \mathbf{[2]}$$

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

$$c = \dots \text{ m s}^{-1} \quad \mathbf{[2]}$$

5.1 Thermal Physics

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 .

$$v_E = \dots\dots\dots \text{ m s}^{-1} \quad [1]$$

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

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

$$T = \dots\dots\dots \text{ K} \quad [3]$$

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

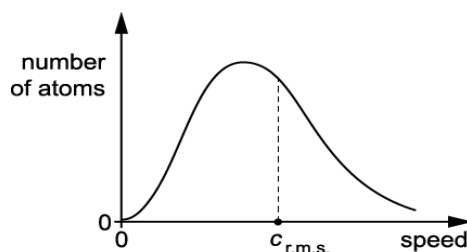


Fig. 1

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