CAMBRIDGE INTERNATIONAL AS & A LEVEL PHYSICS · 9702

# PHYSICS



EXAM QUESTION PACK

## 16 THERMODYNAMICS

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# Chapter 4

# Thermal properties of materials



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51. 9702_m21_qp_42 Q: 3

**(a)** Using a simple kinetic model of matter, describe the structure of a solid.

.....

.....

..... [2]

**(b)** The specific latent heat of vaporisation is much greater than the specific latent heat of fusion for the same substance.
Explain this, in terms of the spacing of molecules.

.....

.....

..... [1]

**(c)** A heater supplies energy at a constant rate to 0.045 kg of a substance. The variation with time of the temperature of the substance is shown in Fig. 3.1. The substance is perfectly insulated from its surroundings.

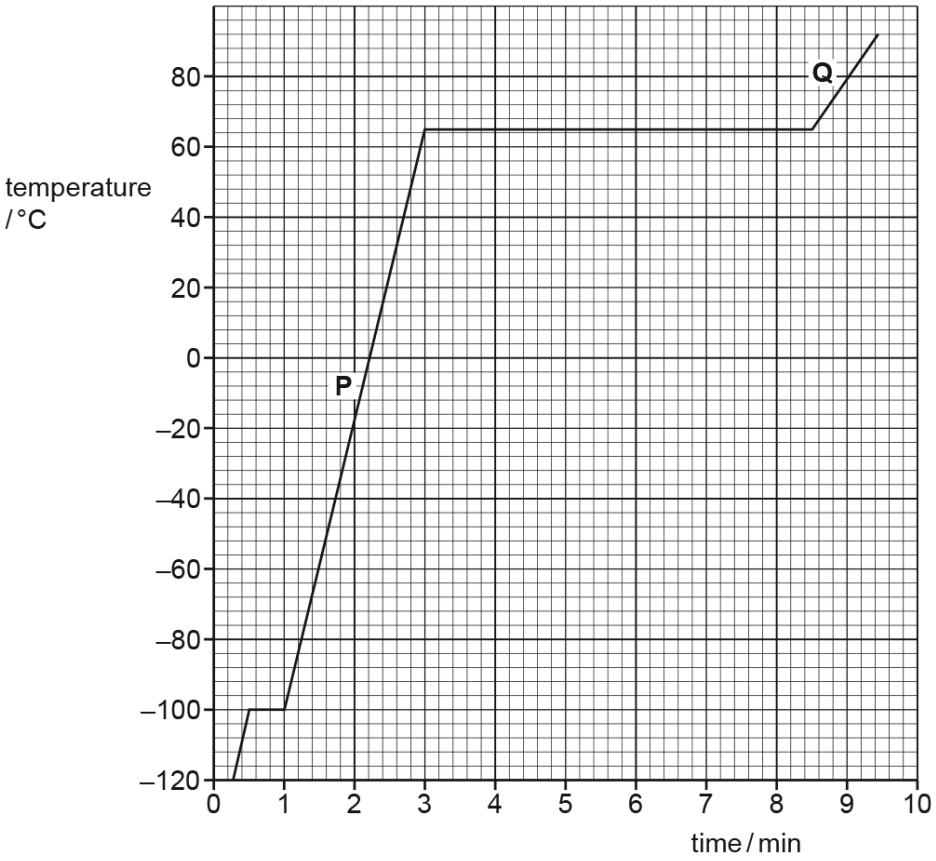



**Fig. 3.1**

**(i)** Determine the temperature at which the substance melts.

temperature = ..... °C [1]

**(ii)** The power of the heater is 150 W.
Use data from Fig. 3.1 to calculate, in $kJ\,kg^{-1}$, the specific latent heat of vaporisation $L$ of the substance.

$L$ = ..... $kJ\,kg^{-1}$ [3]

**(iii)** Suggest what can be deduced from the fact that section **Q** on the graph is less steep than section **P**.

.....

..... [1]

[Total: 8]

---

52. 9702_m20_qp_42 Q: 2

A large container of volume 85 $m^3$ is filled with 110 kg of an ideal gas. The pressure of the gas is $1.0 \times 10^5$ Pa at temperature $T$.

The mass of 1.0 mol of the gas is 32 g.

**(a)** Show that the temperature $T$ of the gas is approximately 300 K.

[3]

**(b)** The temperature of the gas is increased to 350 K at constant volume. The specific heat capacity of the gas for this change is 0.66 $J\,kg^{-1}\,K^{-1}$.

Calculate the energy supplied to the gas by heating.

energy = ..... J [2]

**(c)** Explain how movement of the gas molecules causes pressure in the container.

.....

.....

.....

.....

.....

.....

..... [3]

**(d)** The temperature of a gas depends on the root-mean-square (r.m.s.) speed of its molecules.

Calculate the ratio:

$$\frac{\text{r.m.s. speed of gas molecules at } 350\,\text{K}}{\text{r.m.s. speed of gas molecules at } 300\,\text{K}}.$$

ratio = ..... [2]

[Total: 10]

---

53. 9702_w19_qp_41 Q: 3

**(a)** State what is meant by *specific latent heat*.

.....

.....

..... [2]

**(b)** A student determines the specific latent heat of vaporisation of a liquid using the apparatus illustrated in Fig. 3.1.

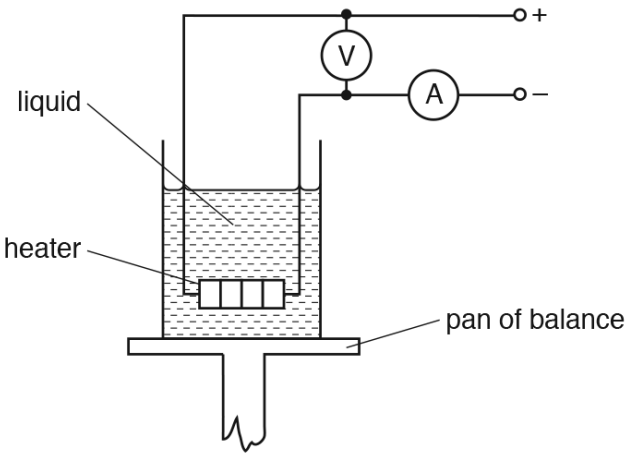



**Fig. 3.1**

The heater is switched on. When the liquid is boiling at a constant rate, the balance reading is noted at 2.0 minute intervals.

After 10 minutes, the current in the heater is reduced and the balance readings are taken for a further 12 minutes.

The readings of the ammeter and of the voltmeter are given in Fig. 3.2.

| | ammeter reading /A | voltmeter reading /V |
|---|---|---|
| from time 0 to time 10 minutes<br>after time 10 minutes | 1.2<br>1.0 | 230<br>190 |

**Fig. 3.2**

The variation with time of the balance reading is shown in Fig. 3.3.

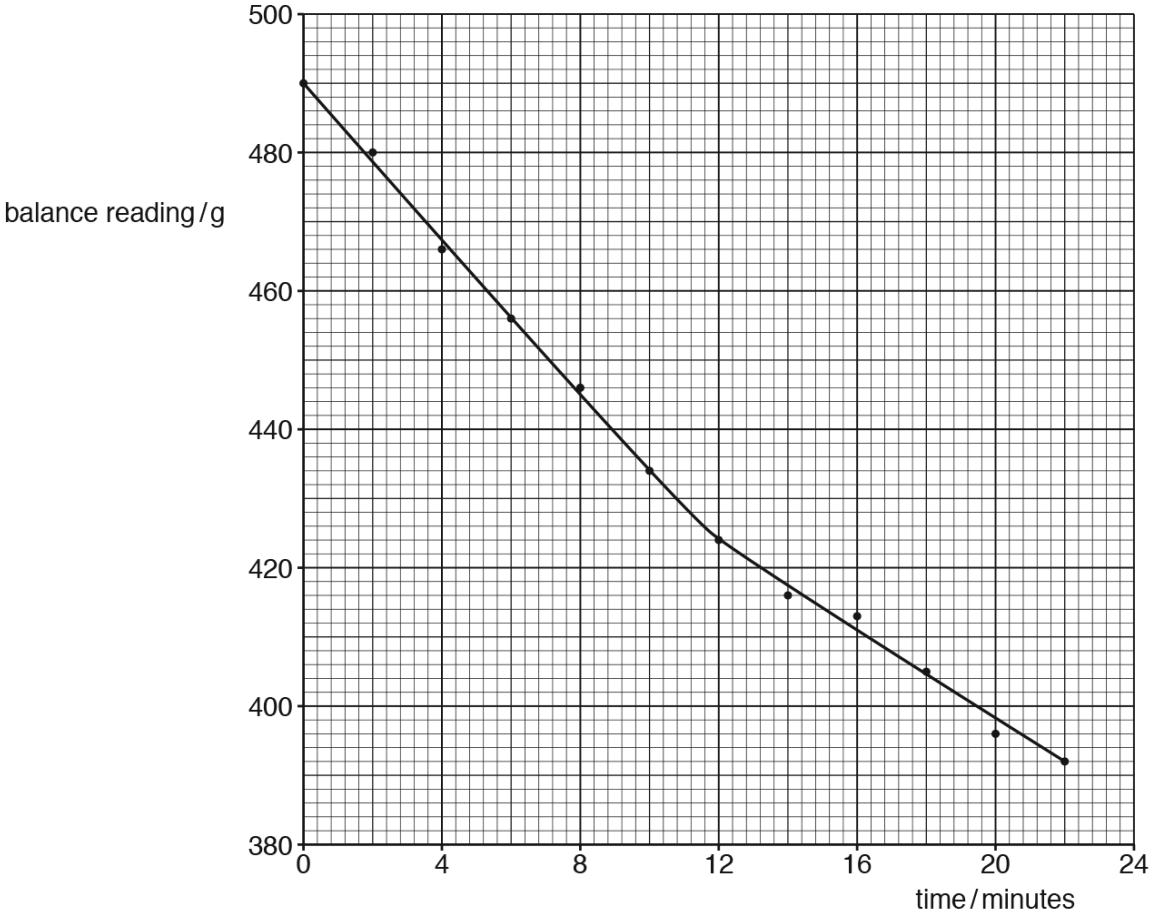



**Fig. 3.3**

**(i)** From time 0 to time 10.0 minutes, the mass of liquid evaporated is 56 g.

Use Fig. 3.3 to determine the mass of liquid evaporated from time 12.0 minutes to time 22.0 minutes.

mass = ..... g [1]

**(ii)** Explain why, although the power of the heater is changed, the rate of loss of thermal energy to the surroundings may be assumed to be constant.

.....

..... [1]

**(iii)** Determine a value for the specific latent heat of vaporisation $L$ of the liquid.

$L$ = ..... $J\,g^{-1}$ [4]

**(iv)** Calculate the rate at which thermal energy is transferred to the surroundings.

rate = ..... W [2]

[Total: 10]

54. 9702_w19_qp_42 Q: 3

**(a)** State what is meant by *specific latent heat*.

.....

.....

..... [2]

**(b)** A student uses the apparatus illustrated in Fig. 3.1 to determine a value for the specific latent heat of fusion of ice.

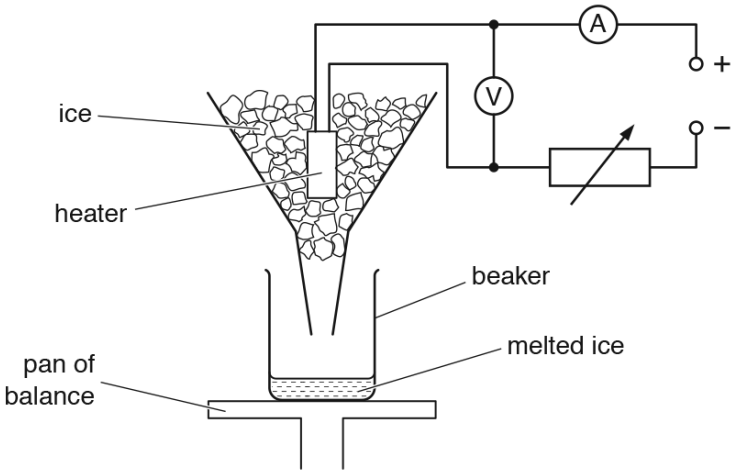



**Fig. 3.1**

The balance reading measures the mass of the beaker and the melted ice (water) in the beaker.

The heater is switched on and pieces of ice at 0 °C are added continuously to the funnel so that the heater is always surrounded by ice.

When water drips out of the funnel at a constant rate, the balance reading is noted at 2.0 minute intervals. After 10 minutes, the current in the heater is increased and the balance readings are taken for a further 12 minutes.

The variation with time of the balance reading is shown in Fig. 3.2.

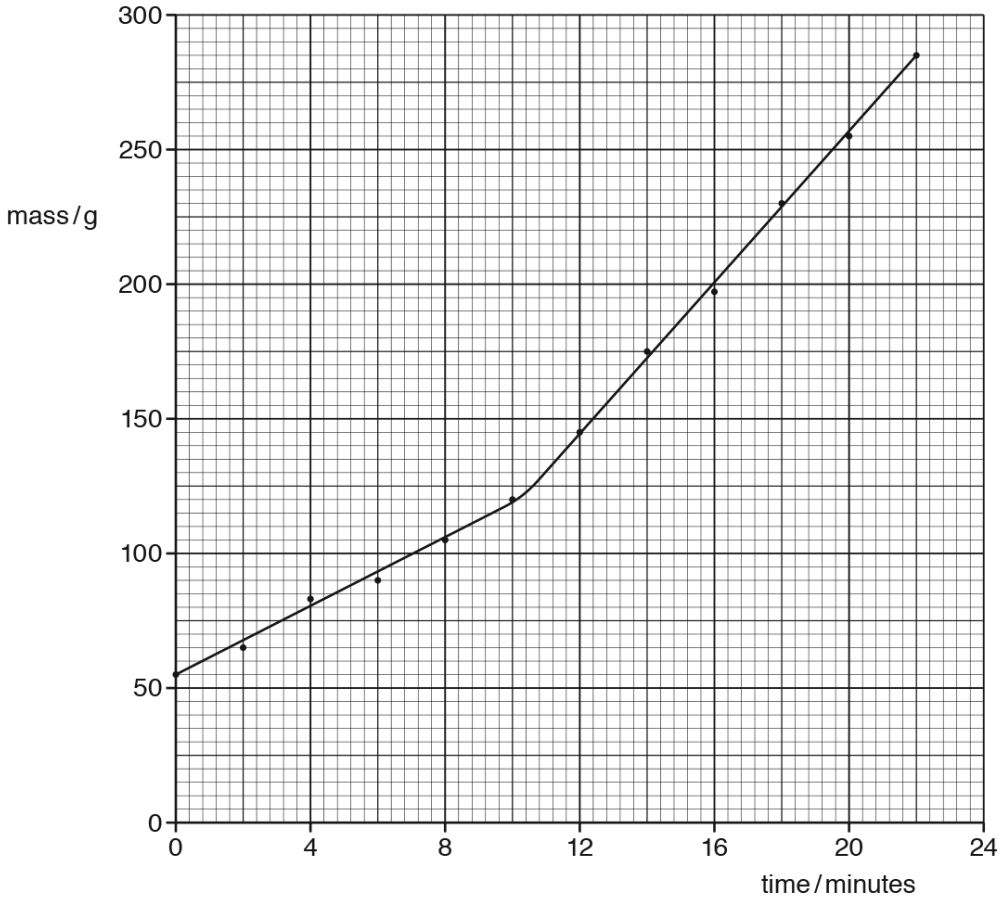



**Fig. 3.2**

The readings of the ammeter and of the voltmeter are shown in Fig. 3.3.

| | ammeter reading /A | voltmeter reading /V |
|---|---|---|
| from time 0 to time 10 minutes<br>after time 10 minutes | 1.8<br>3.6 | 7.3<br>15.1 |

**Fig. 3.3**

**(i)** From time 0 to time 10.0 minutes, 65 g of ice is melted.

Use Fig. 3.2 to determine the mass of ice melted from time 12.0 minutes to time 22.0 minutes.

mass = ..... g [1]

**(ii)** Explain why, although the power of the heater is changed, the rate at which thermal energy is transferred from the surroundings to the ice is constant.

.....

..... [1]

**(iii)** Determine a value for the specific latent heat of fusion $L$ of ice.

$L$ = ..... $J\,g^{-1}$ [4]

**(iv)** Calculate the rate at which thermal energy is transferred from the surroundings to the ice.

rate = ..... W [2]

[Total: 10]

55. 9702_w19_qp_43 Q: 3

**(a)** State what is meant by *specific latent heat*.

.....

.....

..... [2]

**(b)** A student determines the specific latent heat of vaporisation of a liquid using the apparatus illustrated in Fig. 3.1.

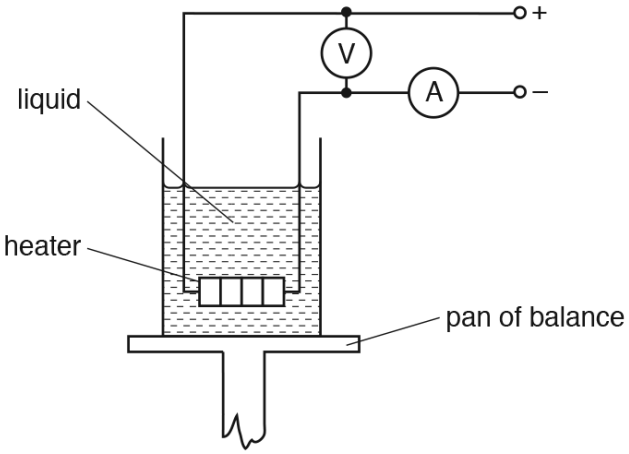



**Fig. 3.1**

The heater is switched on. When the liquid is boiling at a constant rate, the balance reading is noted at 2.0 minute intervals.

After 10 minutes, the current in the heater is reduced and the balance readings are taken for a further 12 minutes.

The readings of the ammeter and of the voltmeter are given in Fig. 3.2.

| | ammeter reading /A | voltmeter reading /V |
|---|---|---|
| from time 0 to time 10 minutes<br>after time 10 minutes | 1.2<br>1.0 | 230<br>190 |

**Fig. 3.2**

The variation with time of the balance reading is shown in Fig. 3.3.

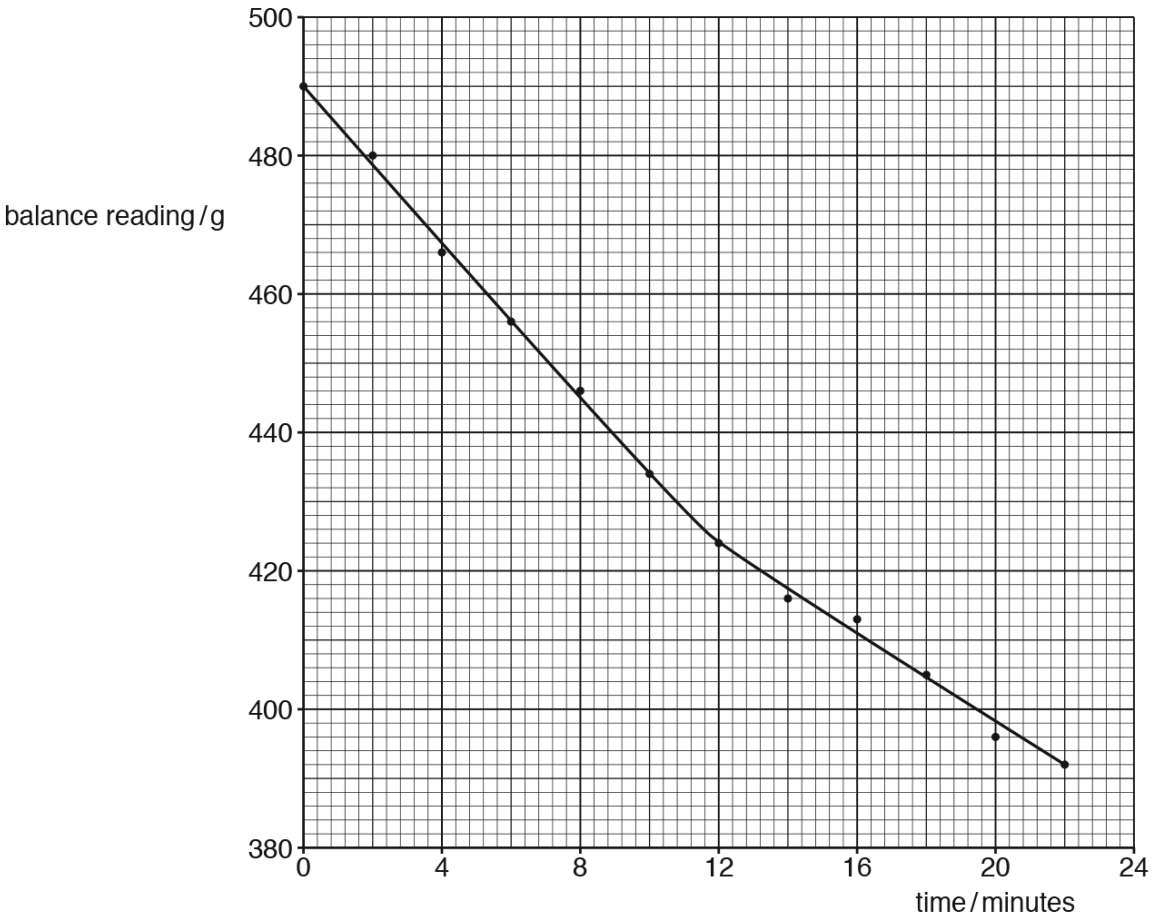



**Fig. 3.3**

**(i)** From time 0 to time 10.0 minutes, the mass of liquid evaporated is 56 g.

Use Fig. 3.3 to determine the mass of liquid evaporated from time 12.0 minutes to time 22.0 minutes.

mass = ..... g [1]

**(ii)** Explain why, although the power of the heater is changed, the rate of loss of thermal energy to the surroundings may be assumed to be constant.

.....

..... [1]

**(iii)** Determine a value for the specific latent heat of vaporisation $L$ of the liquid.

$L$ = ..... $J\,g^{-1}$ [4]

**(iv)** Calculate the rate at which thermal energy is transferred to the surroundings.

rate = ..... W [2]

[Total: 10]

56. 9702_s18_qp_42 Q: 3

**(a)** During melting, a solid becomes liquid with little or no change in volume.

Use kinetic theory to explain why, during the melting process, thermal energy is required although there is no change in temperature.

.....

.....

.....

.....

.....[3]

**(b)** An aluminium can of mass 160 g contains a mass of 330 g of warm water at a temperature of 38 °C, as illustrated in Fig. 3.1.

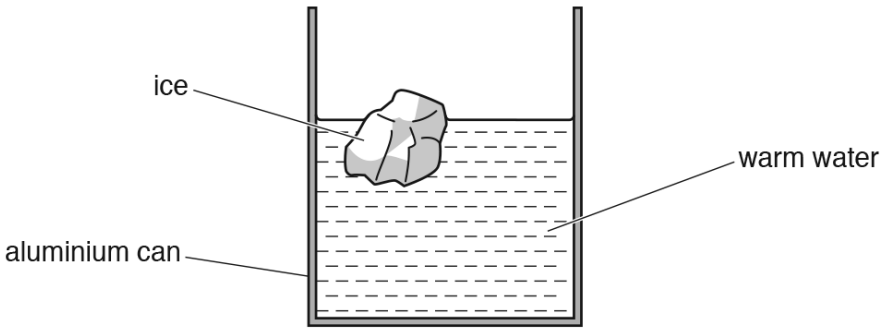



**Fig. 3.1**

A mass of 48 g of ice at –18 °C is taken from a freezer and put in to the water. The ice melts and the final temperature of the can and its contents is 23 °C.

Data for the specific heat capacity $c$ of aluminium, ice and water are given in Fig. 3.2.

| | $c$ / J g$^{-1}$ K$^{-1}$ |
|---|---|
| aluminium | 0.910 |
| ice | 2.10 |
| water | 4.18 |

**Fig. 3.2**

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Assuming no exchange of thermal energy with the surroundings,

**(i)** show that the loss in thermal energy of the can and the warm water is $2.3 \times 10^4$ J,

[2]

**(ii)** use the information in **(i)** to calculate a value $L$ for the specific latent heat of fusion of ice.

$L$ = ..... $\text{J g}^{-1}$ [2]

[Total: 7]

---

57. 9702_w18_qp_42 Q: 3

**(a)** Define *specific latent heat of fusion*.

.....

.....

.....[2]

**(b)** A student sets up the apparatus shown in Fig. 3.1 in order to investigate the melting of ice.

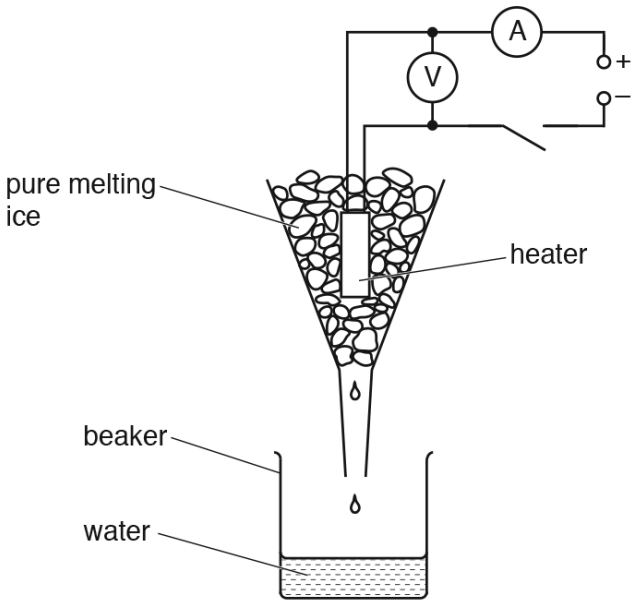



**Fig. 3.1**

The heater is switched on.
When the pure ice is melting at a constant rate, the data shown in Fig. 3.2 are collected.

| voltmeter reading /V | ammeter reading /A | initial mass of beaker plus water/g | final mass of beaker plus water/g | time of collection /minutes |
|---|---|---|---|---|
| 12.8 | 4.60 | 121.5 | 185.0 | 5.00 |

**Fig. 3.2**

The specific latent heat of fusion of ice is $332\,J\,g^{-1}$.

**(i)** State what is observed by the student that shows that the ice is melting at a constant rate.

.....

.....[1]

**(ii)** Use the data in Fig. 3.2 to determine the rate at which

**1.** thermal energy is transferred to the melting ice,

rate = ..... W

**2.** thermal energy is gained from the surroundings.

rate = ..... W
[4]

[Total: 7]

---

58. 9702_s17_qp_42 Q: 2

**(a)** The pressure $p$ and volume $V$ of an ideal gas are related to the density $\rho$ of the gas by the expression

$$p = \frac{1}{3}\rho\langle c^2\rangle.$$

**(i)** State what is meant by the symbol $\langle c^2\rangle$.

.....

.....[1]

**(ii)** Use the expression to show that the mean kinetic energy $E_K$ of a gas molecule is given by

$$E_K = \frac{3}{2}kT$$

where $k$ is the Boltzmann constant and $T$ is the thermodynamic temperature.

[3]

**(b)** **(i)** An ideal gas containing 1.0 mol of molecules is heated at constant volume.
Use the expression in **(a)(ii)** to show that the thermal energy required to raise the temperature of the gas by 1.0 K has a value of $\frac{3}{2}R$, where $R$ is the molar gas constant.

[3]

**(ii)** Nitrogen may be assumed to be an ideal gas. The molar mass of nitrogen gas is $28\,g\,mol^{-1}$. Use the answer in **(b)(i)** to calculate a value for the specific heat capacity, in $J\,kg^{-1}\,K^{-1}$, at constant volume for nitrogen.

specific heat capacity = ..... $J\,kg^{-1}\,K^{-1}$ [2]

[Total: 9]

---

59. 9702_w17_qp_41 Q: 1

**(a)** State

**(i)** what may be deduced from the difference in the temperatures of two objects,

.....

..... [1]

**(ii)** the basic principle by which temperature is measured.

.....

..... [1]

**(b)** By reference to your answer in **(a)(ii)**, explain why two thermometers may not give the same temperature reading for an object.

.....

.....

..... [2]

**(c)** A block of aluminium of mass 670 g is heated at a constant rate of 95 W for 6.0 minutes.
The specific heat capacity of aluminium is 910 $J\,kg^{-1}\,K^{-1}$.
The initial temperature of the block is 24 °C.

**(i)** Assuming that no thermal energy is lost to the surroundings, show that the final temperature of the block is 80 °C.

[3]

**(ii)** In practice, there are energy losses to the surroundings.
The actual variation with time $t$ of the temperature $\theta$ of the block is shown in Fig. 1.1.

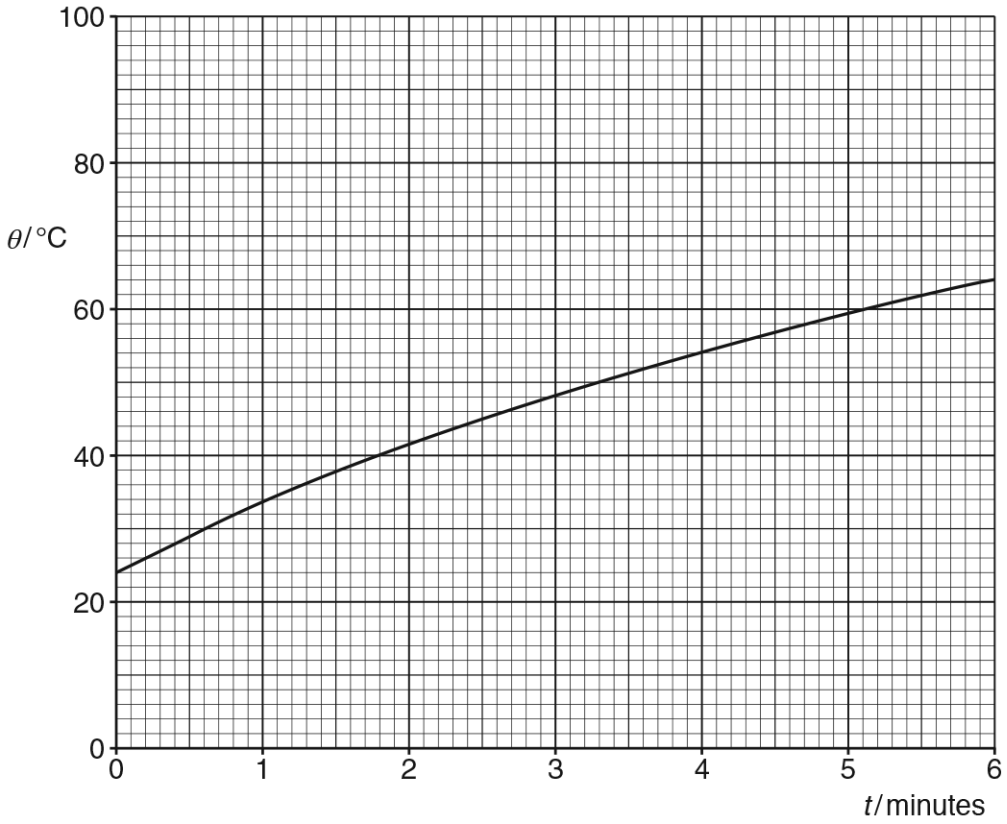



**Fig. 1.1**

**1.** Use the information in **(i)** to draw, on Fig. 1.1, a line to represent the temperature of the block, assuming no energy losses to the surroundings. [1]

**2.** Using Fig. 1.1, calculate the total energy loss to the surroundings during the heating process.

energy loss = ..... J [2]

[Total: 10]

60. 9702_w17_qp_43 Q: 1

**(a)** State

**(i)** what may be deduced from the difference in the temperatures of two objects,

.....

..... [1]

**(ii)** the basic principle by which temperature is measured.

.....

..... [1]

**(b)** By reference to your answer in **(a)(ii)**, explain why two thermometers may not give the same temperature reading for an object.

.....

.....

..... [2]

**(c)** A block of aluminium of mass 670 g is heated at a constant rate of 95 W for 6.0 minutes.
The specific heat capacity of aluminium is 910 $J\,kg^{-1}\,K^{-1}$.
The initial temperature of the block is 24 °C.

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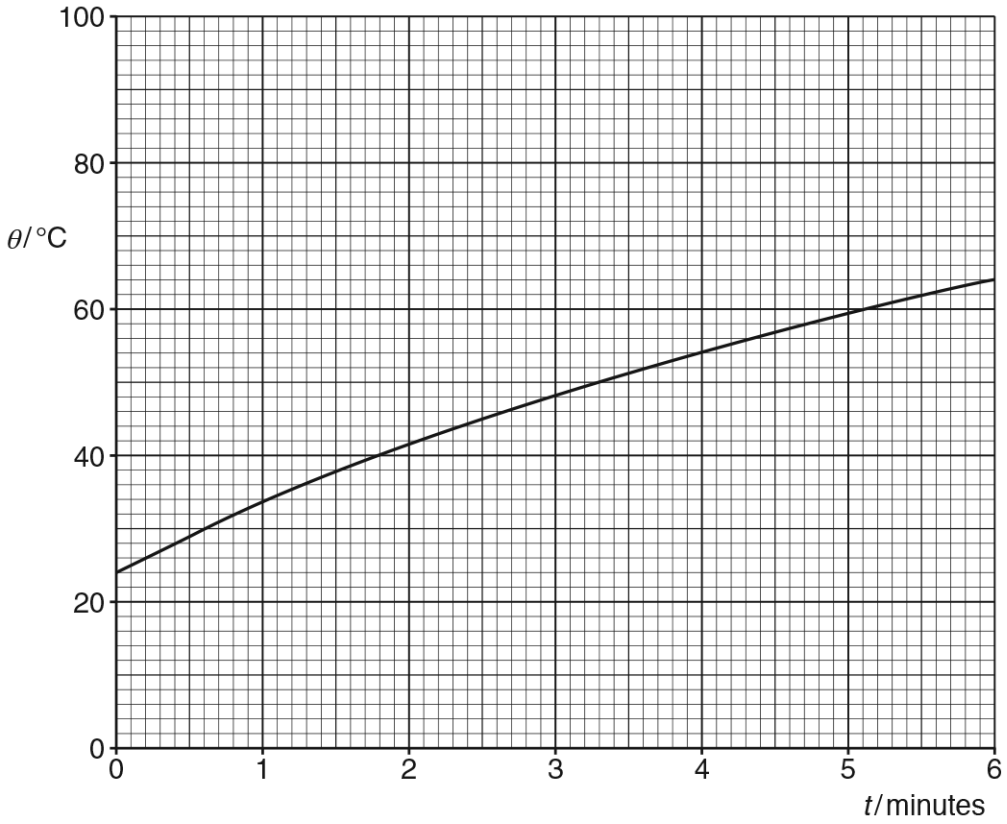



**Fig. 1.1**

**1.** Use the information in **(i)** to draw, on Fig. 1.1, a line to represent the temperature of the block, assuming no energy losses to the surroundings. [1]

**2.** Using Fig. 1.1, calculate the total energy loss to the surroundings during the heating process.

energy loss = ..... J [2]

[Total: 10]

61. 9702_s21_qp_41 Q: 2

An ideal gas is contained in a cylinder by means of a movable frictionless piston, as illustrated in Fig. 2.1.

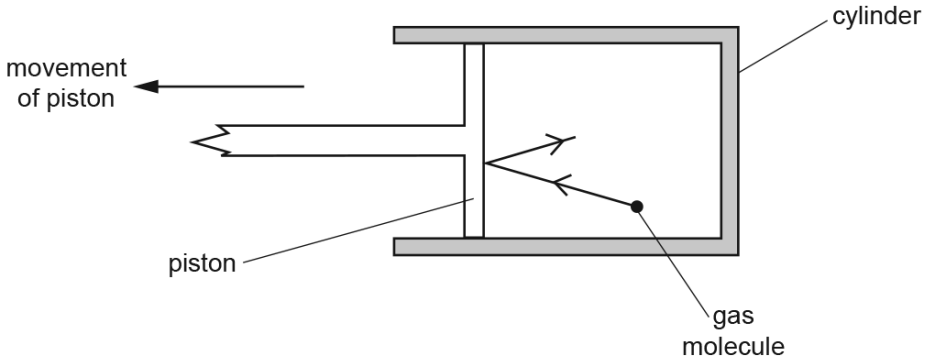



**Fig. 2.1**

Initially, the gas has a volume of $1.8 \times 10^{-3}\,m^3$ at a pressure of $3.3 \times 10^5\,Pa$ and a temperature of 310 K.

**(a)** Show that the number of gas molecules in the cylinder is $1.4 \times 10^{23}$.

[2]

**(b)** Use kinetic theory to explain why, when the piston is moved so that the gas expands, this causes a decrease in the temperature of the gas.

.....

.....

.....

..... [3]

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**(c)** The gas expands so that its volume increases to $2.4 \times 10^{-3}\,m^3$ at a pressure of $2.3 \times 10^5\,Pa$ and a temperature of 288 K, as shown in Fig. 2.2.

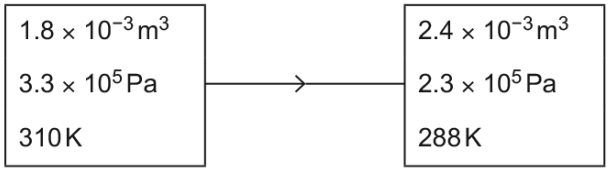



**Fig. 2.2**

**(i)** The average translational kinetic energy $E_K$ of a molecule of an ideal gas is given by

$$E_K = \frac{3}{2}kT$$

where $k$ is the Boltzmann constant and $T$ is the thermodynamic temperature.

Calculate the increase in internal energy $\Delta U$ of the gas during the expansion.

$\Delta U$ = ..... J [3]

**(ii)** The work done by the gas during the expansion is 76 J.

Use your answer in **(i)** to explain whether thermal energy is transferred to or from the gas during the expansion.

.....

.....

..... [2]

[Total: 10]

62. 9702_s21_qp_42 Q: 2

An ideal gas has a volume of $3.1 \times 10^{-3}\,m^3$ at a pressure of $8.5 \times 10^5\,Pa$ and a temperature of 290 K, as shown in Fig. 2.1.

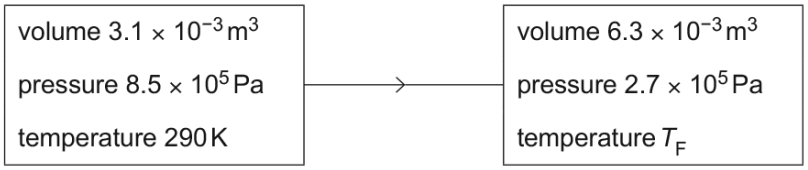



**Fig. 2.1**

The gas suddenly expands to a volume of $6.3 \times 10^{-3}\,m^3$. During the expansion, no thermal energy is transferred. The final pressure of the gas is $2.7 \times 10^5\,Pa$ at temperature $T_F$, as shown in Fig. 2.1.

**(a)** Show that the number of gas molecules is $6.6 \times 10^{23}$.

[3]

**(b)** **(i)** Show that the final temperature $T_F$ of the gas is 190 K.

[1]

**(ii)** The average translational kinetic energy $E_K$ of a molecule of an ideal gas is given by

$$E_K = \frac{3}{2}kT$$

where $T$ is the thermodynamic temperature and $k$ is the Boltzmann constant.

Calculate the increase in internal energy $\Delta U$ of the gas.

$\Delta U$ = ..... J [3]

**(c)** Use the first law of thermodynamics to explain why the external work $w$ done on the gas during the expansion is equal to the increase in internal energy in **(b)(ii)**.

.....

.....

..... [2]

[Total: 9]

63. 9702_s21_qp_43 Q: 2

An ideal gas is contained in a cylinder by means of a movable frictionless piston, as illustrated in Fig. 2.1.

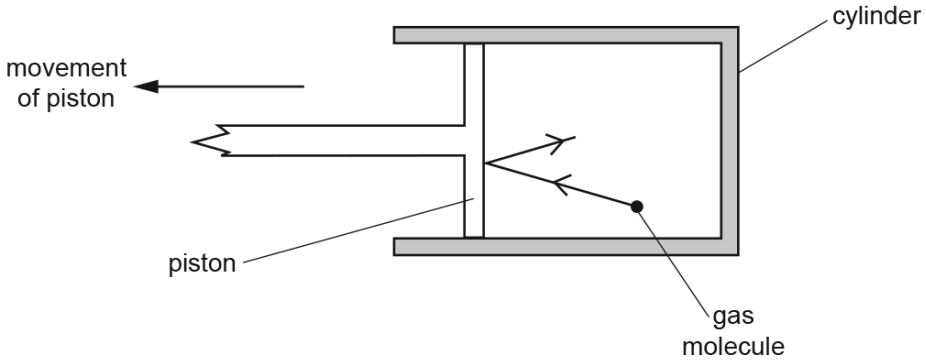



**Fig. 2.1**

Initially, the gas has a volume of $1.8 \times 10^{-3}\,m^3$ at a pressure of $3.3 \times 10^5\,Pa$ and a temperature of 310 K.

**(a)** Show that the number of gas molecules in the cylinder is $1.4 \times 10^{23}$.

[2]

**(b)** Use kinetic theory to explain why, when the piston is moved so that the gas expands, this causes a decrease in the temperature of the gas.

.....

.....

.....

..... [3]

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**(c)** The gas expands so that its volume increases to $2.4 \times 10^{-3}\,m^3$ at a pressure of $2.3 \times 10^5\,Pa$ and a temperature of 288 K, as shown in Fig. 2.2.

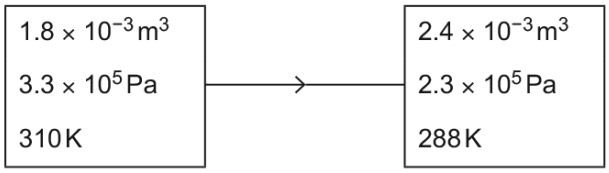



**Fig. 2.2**

**(i)** The average translational kinetic energy $E_K$ of a molecule of an ideal gas is given by

$$E_K = \frac{3}{2}kT$$

where $k$ is the Boltzmann constant and $T$ is the thermodynamic temperature.

Calculate the increase in internal energy $\Delta U$ of the gas during the expansion.

$\Delta U$ = ..... J [3]

**(ii)** The work done by the gas during the expansion is 76 J.

Use your answer in **(i)** to explain whether thermal energy is transferred to or from the gas during the expansion.

.....

.....

..... [2]

[Total: 10]

64. 9702_w21_qp_41 Q: 3

**(a)** Define *specific heat capacity*.

.....

.....

..... [2]

**(b)** A sealed container of fixed volume $V$ contains $N$ molecules, each of mass $m$, of an ideal gas at pressure $p$.

**(i)** State an expression, in terms of $V$, $N$, $p$ and the Boltzmann constant $k$, for the thermodynamic temperature $T$ of the gas.

..... [1]

**(ii)** Show that the mean translational kinetic energy $E_K$ of a molecule of the gas is given by

$$E_K = \frac{3}{2}kT.$$

[2]

**(iii)** Explain why the internal energy of the gas is equal to the total kinetic energy of the molecules.

.....

.....

..... [2]

**(c)** The gas in **(b)** is supplied with thermal energy $Q$.

**(i)** Explain, with reference to the first law of thermodynamics, why the increase in internal energy of the gas is $Q$.

.....

.....

..... [2]

**(ii)** Use the expression in **(b)(ii)** and the information in **(c)(i)** to show that the specific heat capacity $c$ of the gas is given by

$$c = \frac{3k}{2m}.$$

[2]

**(d)** The container in **(b)** is now replaced with one that does not have a fixed volume. Instead, the gas is able to expand, so that the pressure of the gas remains constant as thermal energy is supplied.

Suggest, with a reason, how the specific heat capacity of the gas would now compare with the value in **(c)(ii)**.

.....

.....

.....

..... [2]

[Total: 13]

65. 9702_w21_qp_43 Q: 3

**(a)** Define *specific heat capacity*.

.....

.....

..... [2]

**(b)** A sealed container of fixed volume $V$ contains $N$ molecules, each of mass $m$, of an ideal gas at pressure $p$.

**(i)** State an expression, in terms of $V$, $N$, $p$ and the Boltzmann constant $k$, for the thermodynamic temperature $T$ of the gas.

..... [1]

**(ii)** Show that the mean translational kinetic energy $E_K$ of a molecule of the gas is given by

$$E_K = \frac{3}{2}kT.$$

[2]

**(iii)** Explain why the internal energy of the gas is equal to the total kinetic energy of the molecules.

.....

.....

..... [2]

**(c)** The gas in **(b)** is supplied with thermal energy $Q$.

**(i)** Explain, with reference to the first law of thermodynamics, why the increase in internal energy of the gas is $Q$.

.....

.....

..... [2]

**(ii)** Use the expression in **(b)(ii)** and the information in **(c)(i)** to show that the specific heat capacity $c$ of the gas is given by

$$c = \frac{3k}{2m}.$$

[2]

**(d)** The container in **(b)** is now replaced with one that does not have a fixed volume. Instead, the gas is able to expand, so that the pressure of the gas remains constant as thermal energy is supplied.

Suggest, with a reason, how the specific heat capacity of the gas would now compare with the value in **(c)(ii)**.

.....

.....

.....

..... [2]

[Total: 13]

66. 9702_s20_qp_41 Q: 2

**(a)** State what is meant by the *internal energy* of a system.

.....

.....

.....

..... [2]

**(b)** By reference to intermolecular forces, explain why the change in internal energy of an ideal gas is equal to the change in total kinetic energy of its molecules.

.....

.....

..... [2]

**(c)** State and explain the change, if any, in the internal energy of a solid metal ball as it falls under gravity in a vacuum.

.....

.....

.....

..... [3]

[Total: 7]

---

67. 9702_s20_qp_42 Q: 3

By reference to the first law of thermodynamics, state and explain the change, if any, in the internal energy of:

**(a)** a lump of solid lead as it melts at constant temperature

.....

.....

.....

.....

..... [3]

**(b)** some gas in a toy balloon when the balloon bursts and no thermal energy enters or leaves the gas.

.....

.....

.....

.....

..... [3]

[Total: 6]

---

68. 9702_s20_qp_43 Q: 2

**(a)** State what is meant by the *internal energy* of a system.

.....

.....

.....

..... [2]

**(b)** By reference to intermolecular forces, explain why the change in internal energy of an ideal gas is equal to the change in total kinetic energy of its molecules.

.....

.....

..... [2]

**(c)** State and explain the change, if any, in the internal energy of a solid metal ball as it falls under gravity in a vacuum.

.....

.....

.....

..... [3]

[Total: 7]

69. 9702_s19_qp_41 Q: 2

A fixed mass of an ideal gas has volume 210 cm$^3$ at pressure $3.0 \times 10^5$ Pa and temperature 270 K.

The volume of the gas is reduced at constant pressure to 140 cm$^3$, as shown in Fig. 2.1.

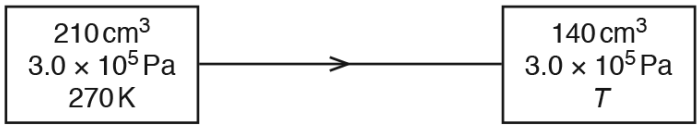



**Fig. 2.1**

The final temperature of the gas is $T$.

**(a)** Determine:

**(i)** the amount of gas

amount = ..... mol [3]

**(ii)** the final temperature $T$ of the gas

$T$ = .....K [2]

**(iii)** the external work done on the gas.

work done = ..... J [2]

**(b)** For this change in volume and temperature of the gas, the thermal energy transferred is 53 J.

Determine $\Delta U$, the change in internal energy of the gas.

$\Delta U =$ ..... J [3]

[Total: 10]

---

70. 9702_s19_qp_42 Q: 2

**(a)** The first law of thermodynamics may be expressed in the form

$$\Delta U = q + w.$$

**(i)** State, for a system, what is meant by:

**1.** $+q$

.....

.....

**2.** $+w$.

.....

.....

[2]

**(ii)** State what is represented by a negative value of $\Delta U$.

.....

.....[1]

**(b)** An ideal gas, sealed in a container, undergoes the cycle of changes shown in Fig. 2.1.

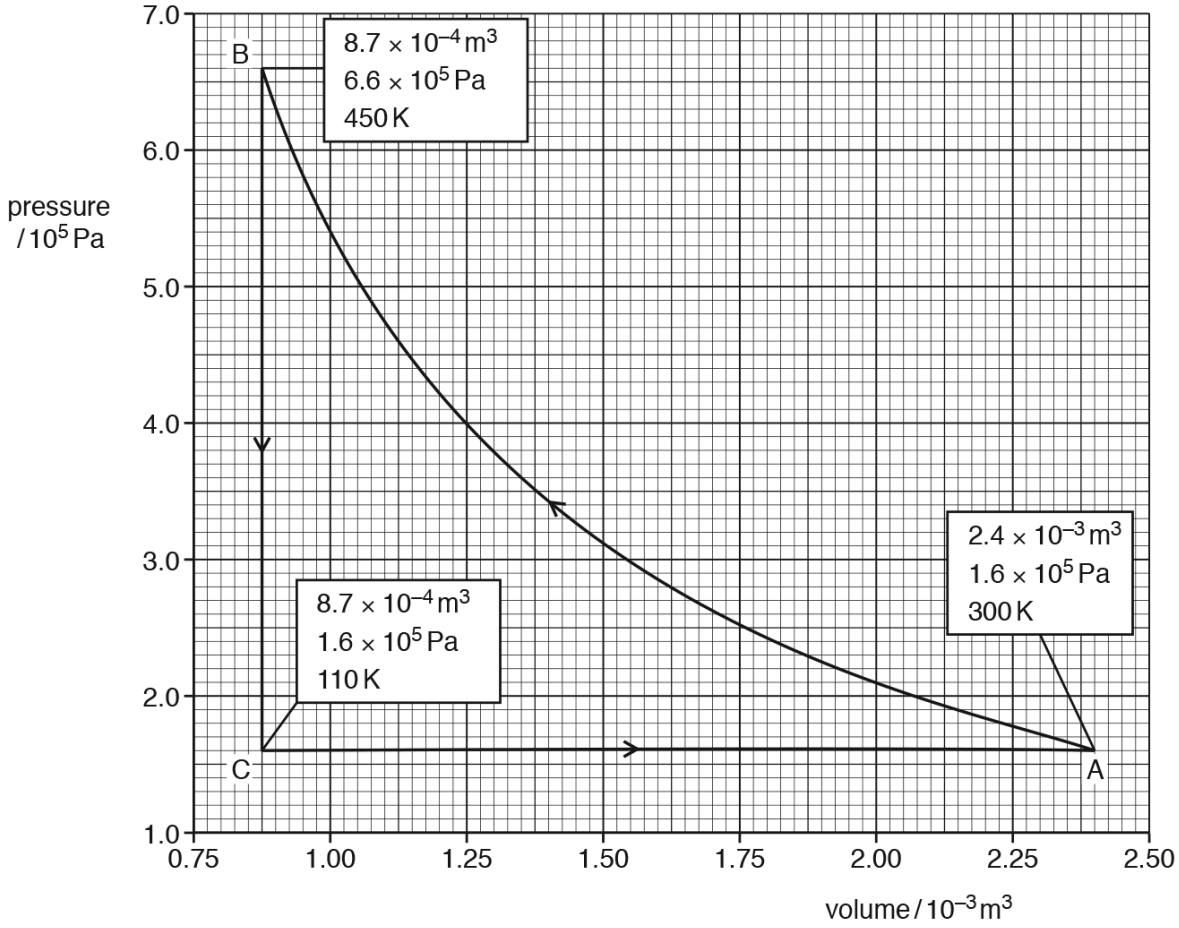



**Fig. 2.1**

At point A, the gas has volume $2.4 \times 10^{-3}\,m^3$, pressure $1.6 \times 10^5\,Pa$ and temperature 300 K.

The gas is compressed suddenly so that no thermal energy enters or leaves the gas during the compression. The amount of work done is 480 J so that, at point B, the gas has volume $8.7 \times 10^{-4}\,m^3$, pressure $6.6 \times 10^5\,Pa$ and temperature 450 K.

The gas is now cooled at constant volume so that, between points B and C, 1100 J of thermal energy is transferred. At point C, the gas has pressure $1.6 \times 10^5\,Pa$ and temperature 110 K.

Finally, the gas is returned to point A.

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**(i)** State and explain the total change in internal energy of the gas for one complete cycle ABCA.

.....

.....

.....[2]

**(ii)** Calculate the external work done on the gas during the expansion from point C to point A.

work done = ..... J [2]

**(iii)** Complete Fig. 2.2 for the changes from:

**1.** point A to point B

**2.** point B to point C

**3.** point C to point A.

| change | $+q$/J | $+w$/J | $\Delta U$/J |
|---|---|---|---|
| A → B | ..... | ..... | ..... |
| B → C | ..... | ..... | ..... |
| C → A | ..... | ..... | ..... |

**Fig. 2.2**

[4]

[Total: 11]

71. 9702_s19_qp_43 Q: 2

A fixed mass of an ideal gas has volume 210 cm$^3$ at pressure 3.0 × 10$^5$ Pa and temperature 270 K.

The volume of the gas is reduced at constant pressure to 140 cm$^3$, as shown in Fig. 2.1.

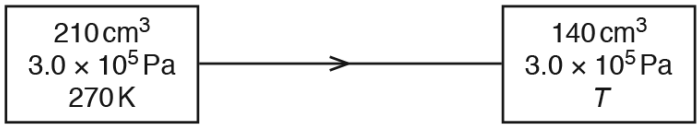



**Fig. 2.1**

The final temperature of the gas is $T$.

**(a)** Determine:

**(i)** the amount of gas

amount = ..... mol [3]

**(ii)** the final temperature $T$ of the gas

$T$ = .....K [2]

**(iii)** the external work done on the gas.

work done = ..... J [2]

**(b)** For this change in volume and temperature of the gas, the thermal energy transferred is 53 J.

Determine $\Delta U$, the change in internal energy of the gas.

$\Delta U =$ ..... J [3]

[Total: 10]

72. 9702_w19_qp_42 Q: 2

**(a)** Smoke particles are suspended in still air. Brownian motion of the smoke particles is seen through a microscope.

Describe:

**(i)** what is seen through the microscope

.....

..... [1]

**(ii)** how Brownian motion provides evidence for the nature of the movement of gas molecules.

.....

.....

..... [2]

**(b)** A fixed mass of an ideal gas has volume $2.40 \times 10^3\,\text{cm}^3$ at pressure $3.51 \times 10^5\,\text{Pa}$ and temperature 290 K. The gas is heated at constant volume until the temperature is 310 K at pressure $3.75 \times 10^5\,\text{Pa}$, as illustrated in Fig. 2.1.

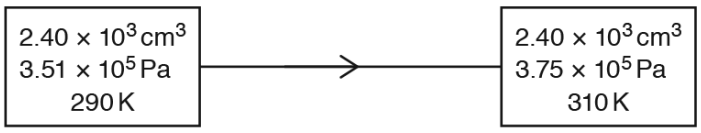



**Fig. 2.1**

The quantity of thermal energy required to raise the temperature of 1.00 mol of the gas by 1.00 K at constant volume is 12.5 J.

Calculate, to three significant figures:

**(i)** the amount, in mol, of the gas

amount = ..... mol [3]

**(ii)** the thermal energy transfer during the change.

energy transfer = ..... J [2]

**(c)** For the change in the gas in **(b)**, state:

**(i)** the quantity of external work done on the gas

work done = ..... J [1]

**(ii)** the change in internal energy, with the direction of this change.

change = ..... J

direction .....
[2]

[Total: 11]

---

73. 9702_m18_qp_42 Q: 2

A cylinder contains 5.12 mol of an ideal gas at pressure of $5.60 \times 10^5$ Pa and volume $3.80 \times 10^4$ cm$^3$.

**(a)** Determine the temperature of the gas.

temperature = ..... K [2]

**(b)** The average kinetic energy $E_K$ of a molecule of the gas is given by the expression

$$E_K = \frac{3}{2} kT$$

where $k$ is the Boltzmann constant and $T$ is the thermodynamic temperature.

The gas is heated at constant pressure so that its temperature rises by 125 K.

**(i)** Use your answer in **(a)** to determine the new volume of the gas.

volume = ..... cm$^3$ [2]

**(ii)** Calculate the increase in internal energy of the gas. Explain your working.

increase in internal energy = ..... J [3]

**(c)** **(i)** Use your answer in **(b)(i)** to determine the external work done during the expansion of the gas.

work done = .....J [2]

**(ii)** Calculate the total thermal energy required to heat the gas in **(b)**.

energy = .....J [1]

[Total: 10]

---

74. 9702_s18_qp_41 Q: 3

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

.....

.....

.....

.....[2]

**(ii)** Explain why, for an ideal gas, the change in internal energy is directly proportional to the change in thermodynamic temperature of the gas.

.....

.....

.....

.....

.....[3]

**(b)** A cylinder of volume $1.8 \times 10^4\,\text{cm}^3$ contains helium gas at pressure $6.4 \times 10^6\,\text{Pa}$ and temperature 25 °C.
Helium gas may be considered to be an ideal gas consisting of single atoms.

Calculate the number of helium atoms in the cylinder.

number = .....[3]

[Total: 8]

75. 9702_s18_qp_43 Q: 3

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

.....

.....

.....

.....[2]

**(ii)** Explain why, for an ideal gas, the change in internal energy is directly proportional to the change in thermodynamic temperature of the gas.

.....

.....

.....

.....

.....[3]

**(b)** A cylinder of volume $1.8 \times 10^4\,\text{cm}^3$ contains helium gas at pressure $6.4 \times 10^6\,\text{Pa}$ and temperature 25 °C.
Helium gas may be considered to be an ideal gas consisting of single atoms.

Calculate the number of helium atoms in the cylinder.

number = .....[3]

[Total: 8]

76. 9702_w18_qp_43 Q: 2

**(a)** State what is meant by the *internal energy* of a system.

.....

.....

.....

.....[2]

**(b)** An ideal gas undergoes a cycle of changes as shown in Fig. 2.1.

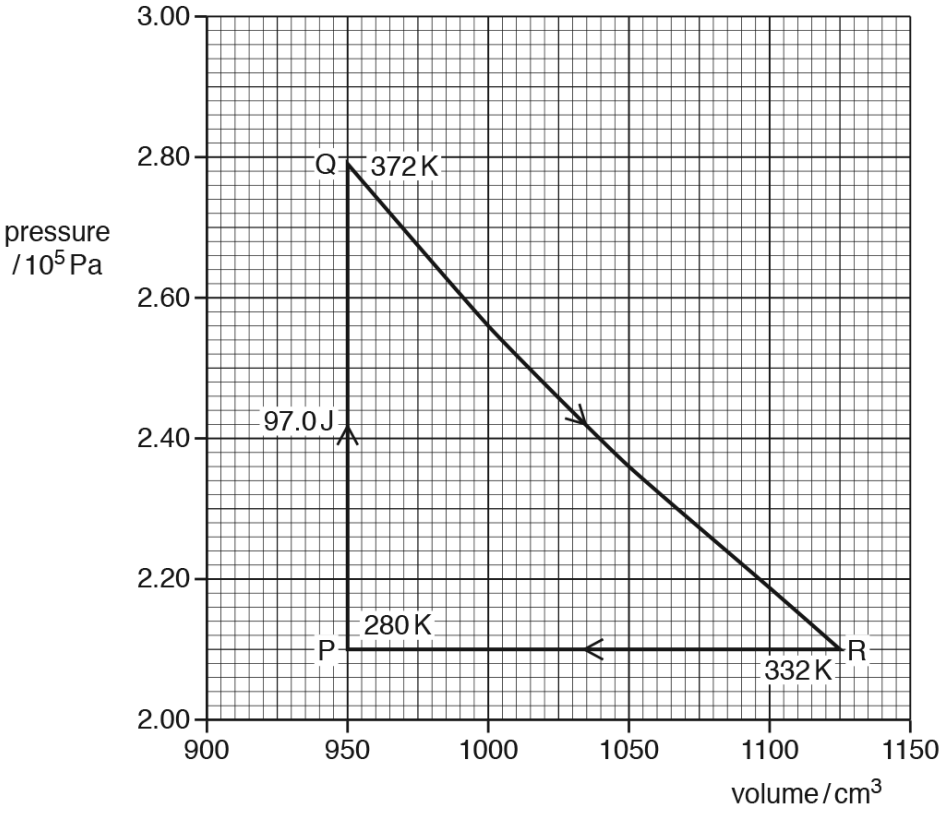



**Fig. 2.1**

At point P, the gas has volume 950 $cm^3$, pressure $2.10 \times 10^5$ Pa and temperature 280 K.

The gas is heated at constant volume and 97.0 J of thermal energy is transferred to the gas. Its pressure and temperature change so that the gas is at point Q on Fig. 2.1.

The gas then undergoes the change from point Q to point R and then from point R back to point P, as shown on Fig. 2.1.

Some energy changes that take place during the cycle PQRP are shown in Fig. 2.2.

| | change P → Q | change Q → R | change R → P |
|---|---|---|---|
| thermal energy transferred to gas/J | +97.0 | 0 | ..... |
| work done on gas/J | ..... | −42.5 | +37.0 |
| increase in internal energy of gas/J | ..... | ..... | ..... |

**Fig. 2.2**

**(i)** State the total change in internal energy of the gas during the complete cycle PQRP. Explain your answer.

.....

.....

.....[2]

**(ii)** On Fig. 2.2, complete the energy changes for the gas during

**1.** the change P → Q,

**2.** the change Q → R,

**3.** the change R → P.

[5]

[Total: 9]

77. 9702_m17_qp_42 Q: 2

**(a)** The first law of thermodynamics can be represented by the expression

$$\Delta U = q + w.$$

State what is meant by the symbols in the expression.

$+\Delta U$ .....

$+q$ .....

$+w$ .....

[2]

**(b)** A fixed mass of an ideal gas undergoes a cycle ABCA of changes, as shown in Fig. 2.1.

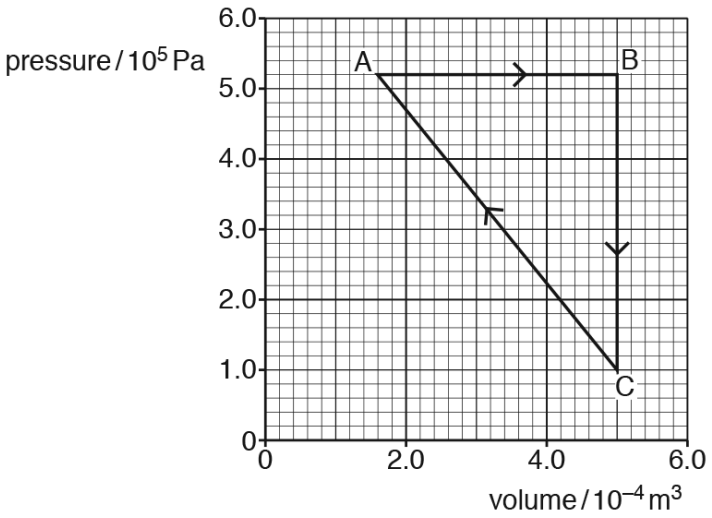



**Fig. 2.1**

**(i)** During the change from A to B, the energy supplied to the gas by heating is 442 J.

Use the first law of thermodynamics to show that the internal energy of the gas increases by 265 J.

[2]

**(ii)** During the change from B to C, the internal energy of the gas decreases by 313 J.

By considering molecular energy, state and explain qualitatively the change, if any, in the temperature of the gas.

.....

.....

.....

.....

.....[3]

**(iii)** For the change from C to A, use the data in **(b)(i)** and **(b)(ii)** to calculate the change in internal energy.

change in internal energy = .....J [1]

**(iv)** The temperature of the gas at point A is 227 °C. Calculate the number of molecules in the fixed mass of the gas.

number = .....[2]

[Total: 10]

78. 9702_w17_qp_42 Q: 2

**(a)** State what is meant by *specific latent heat*.

.....

.....

.....[2]

**(b)** A beaker of boiling water is placed on the pan of a balance, as illustrated in Fig. 2.1.

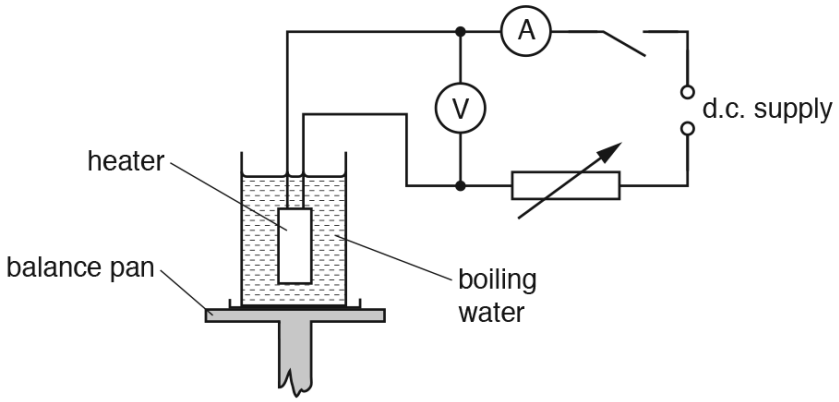



**Fig. 2.1**

The water is maintained at its boiling point by means of a heater.
The change $M$ in the balance reading in 300 s is determined for two different input powers to the heater.
The results are shown in Fig. 2.2.

| voltmeter reading / V | ammeter reading /A | $M$/g |
|---|---|---|
| 11.5<br>14.2 | 5.2<br>6.4 | 5.0<br>9.1 |

**Fig. 2.2**

**(i)** Energy is supplied continuously by the heater.
State where, in this experiment,

**1.** external work is done,

.....

.....

**2.** internal energy increases. Explain your answer.

.....

.....

.....
[3]

**(ii)** Use data in Fig. 2.2 to determine the specific latent heat of vaporisation of water.

specific latent heat = ..... $J\,g^{-1}$ [3]

[Total: 8]

---

79. 9702_m16_qp_42 Q: 2

**(a)** State

**(i)** what is meant by *internal energy*,

.....

.....

.....[2]

**(ii)** the basic assumption of the kinetic theory of gases that leads to the conclusion that there is zero potential energy between the molecules of an ideal gas.

.....

.....[1]

**(b)** The pressure $p$ and volume $V$ of an ideal gas are related by

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

where $N$ is the number of molecules, $m$ is the mass of a molecule and $\langle c^2 \rangle$ is the mean-square speed of the molecules.

Use this equation to show that the mean kinetic energy $\langle E_K \rangle$ of a molecule is given by

$$\langle E_K \rangle = \frac{3}{2} kT$$

where $k$ is the Boltzmann constant and $T$ is the thermodynamic temperature.

[3]

**(c)** A cylinder contains 17 g of oxygen gas at a temperature of 12 °C. The mass of 1.0 mol of oxygen gas is 32 g. It may be assumed that the oxygen behaves as an ideal gas.

Calculate, for the oxygen gas in the cylinder,

**(i)** the mean kinetic energy of a molecule,

mean kinetic energy = .....J [2]

**(ii)** the number of molecules,

number = .....[2]

**(iii)** the total internal energy.

internal energy = .....J [1]

[Total: 11]

80. 9702_w16_qp_41 Q: 2

An ideal gas initially has pressure $1.0 \times 10^5$ Pa, volume $4.0 \times 10^{-4}$ m$^3$ and temperature 300 K, as illustrated in Fig. 2.1.

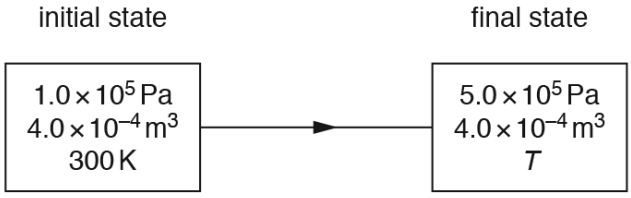



**Fig. 2.1**

A change in energy of the gas of 240 J results in an increase of pressure to a final value of $5.0 \times 10^5$ Pa at constant volume.
The thermodynamic temperature becomes $T$.

**(a)** Calculate

**(i)** the temperature $T$,

$T$ = ..... K [2]

**(ii)** the amount of gas.

amount = ..... mol [2]

**(b)** The increase in internal energy $\Delta U$ of a system may be represented by the expression

$$\Delta U = q + w.$$

**(i)** State what is meant by the symbol

**1.** $+q$,

.....

**2.** $+w$.

.....
[2]

**(ii)** State, for the gas in **(a)**, the value of

**1.** $\Delta U$,

$\Delta U$ = .....J

**2.** $+q$,

$+q$ = .....J

**3.** $+w$.

$+w$ = .....J
[3]

[Total: 9]

---

81. 9702_w16_qp_42 Q: 3

**(a)** State what is meant by the *internal energy* of a system.

.....

.....

.....[2]

**(b)** Explain, by reference to work done and heating, whether the internal energy of the following increases, decreases or remains constant:

**(i)** the gas in a toy balloon when the balloon bursts suddenly,

.....

.....

.....

.....[3]

**(ii)** ice melting at constant temperature and at atmospheric pressure to form water that is more dense than the ice.

.....

.....

.....

.....[3]

[Total: 8]

82. 9702_w16_qp_43 Q: 2

An ideal gas initially has pressure $1.0 \times 10^5$ Pa, volume $4.0 \times 10^{-4}$ m$^3$ and temperature 300 K, as illustrated in Fig. 2.1.




**Fig. 2.1**

A change in energy of the gas of 240 J results in an increase of pressure to a final value of $5.0 \times 10^5$ Pa at constant volume.
The thermodynamic temperature becomes $T$.

**(a)** Calculate

**(i)** the temperature $T$,

$T$ = ..... K [2]

**(ii)** the amount of gas.

amount = ..... mol [2]

**(b)** The increase in internal energy $\Delta U$ of a system may be represented by the expression

$$\Delta U = q + w.$$

**(i)** State what is meant by the symbol

**1.** $+q$,

.....

**2.** $+w$.

.....
[2]

**(ii)** State, for the gas in **(a)**, the value of

**1.** $\Delta U$,

$\Delta U$ = .....J

**2.** $+q$,

$+q$ = .....J

**3.** $+w$.

$+w$ = .....J
[3]

[Total: 9]

---

# Q1.

2 **(a)** On Fig. 2.1, place a tick (✓) against those changes where the internal energy of the body is increasing. [2]

| | |
|---|---|
| water freezing at constant temperature | ..... |
| a stone falling under gravity in a vacuum | ..... |
| water evaporating at constant temperature | ..... |
| stretching a wire at constant temperature | ..... |

**Fig. 2.1**

**(b)** A jeweller wishes to harden a sample of pure gold by mixing it with some silver so that the mixture contains 5.0% silver by weight. The jeweller melts some pure gold and then adds the correct weight of silver. The initial temperature of the silver is 27 °C. Use the data of Fig. 2.2 to calculate the initial temperature of the pure gold so that the final mixture is at the melting point of pure gold.

| | gold | silver |
|---|---|---|
| melting point / K | 1340 | 1240 |
| specific heat capacity (solid or liquid) / $J\,kg^{-1}\,K^{-1}$ | 129 | 235 |
| specific latent heat of fusion / $kJ\,kg^{-1}$ | 628 | 105 |

**Fig. 2.2**

temperature = ..... K [5]

**(c)** Suggest a suitable thermometer for the measurement of the initial temperature of the gold in **(b)**.

..... [1]

## Q2.

USE

**6** The first law of thermodynamics may be expressed in the form

$$\Delta U = q + w,$$

where $U$ is the internal energy of the system,
$\Delta U$ is the increase in internal energy,
$q$ is the thermal energy supplied to the system,
$w$ is the work done on the system.

Complete Fig. 6.1 for each of the processes shown. Write down the symbol '+' for an increase, the symbol '–' to indicate a decrease and the symbol '0' for no change, as appropriate.

| | $U$ | $q$ | $w$ |
|---|---|---|---|
| the compression of an ideal gas at constant temperature | | | |
| the heating of a solid with no expansion | | | |
| the melting of ice at 0 °C to give water at 0 °C<br>(Note: ice is less dense than water) | | | |

[6]

**Fig. 6.1**

## Q3.

3 **(a)** Define *specific latent heat of fusion*.

.....

.....

.....[2]

**(b)** A mass of 24 g of ice at –15 °C is taken from a freezer and placed in a beaker containing 200 g of water at 28 °C. Data for ice and for water are given in Fig. 3.1.

| | specific heat capacity / J kg$^{-1}$ K$^{-1}$ | specific latent heat of fusion / J kg$^{-1}$ |
|---|---|---|
| ice | $2.1 \times 10^3$ | $3.3 \times 10^5$ |
| water | $4.2 \times 10^3$ | – |

**Fig. 3.1**

**(i)** Calculate the quantity of thermal energy required to convert the ice at –15 °C to water at 0 °C.

energy = ..... J [3]

**(ii)** Assuming that the beaker has negligible mass, calculate the final temperature of the water in the beaker.

temperature = ..... °C [3]

**Q4.**

Use

3 The electrical resistance of a thermistor is to be used to measure temperatures in the range 12 °C to 24 °C. Fig. 3.1 shows the variation with temperature, measured in degrees Celsius, of the resistance of the thermistor.

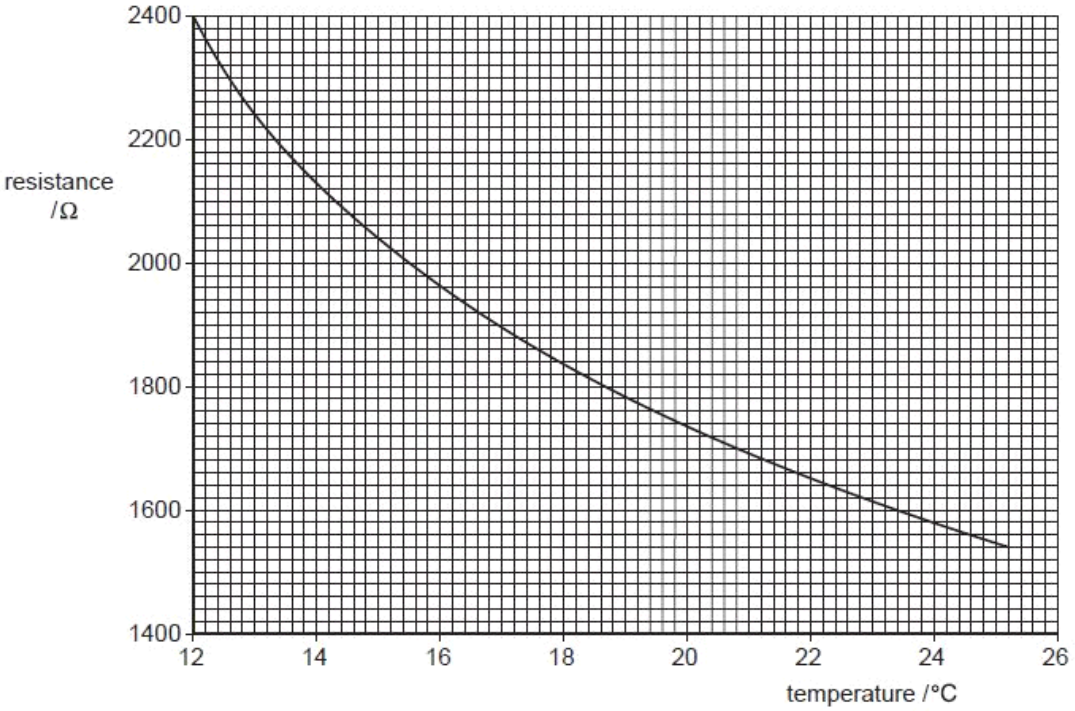



**Fig. 3.1**

**(a)** State and explain the feature of Fig. 3.1 which shows that the thermometer has a sensitivity that varies with temperature.

.....

.....

..... [2]

**(b)** At one particular temperature, the resistance of the thermistor is 2040 ± 20 Ω.

Determine this temperature, in kelvin, to an appropriate number of decimal places.

temperature = ..... K [3]

**Q5.**

**2** **(a)** Use the kinetic theory of matter to explain why melting requires energy but there is no change in temperature.

.....

.....

.....

..... [3]

**(b)** Define *specific latent heat of fusion*.

.....

.....

..... [2]

**(c)** A block of ice at 0 °C has a hollow in its top surface, as illustrated in Fig. 2.1.

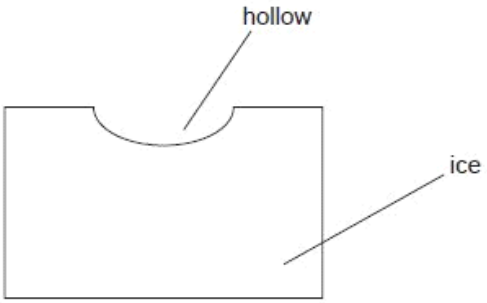



**Fig. 2.1**

A mass of 160 g of water at 100 °C is poured into the hollow. The water has specific heat capacity 4.20 kJ kg$^{-1}$ K$^{-1}$. Some of the ice melts and the final mass of water in the hollow is 365 g.

**(i)** Assuming no heat gain from the atmosphere, calculate a value, in kJ kg$^{-1}$, for the specific latent heat of fusion of ice.

specific latent heat = ..... kJ kg$^{-1}$ [3]

**(ii)** In practice, heat is gained from the atmosphere during the experiment. This means that your answer to **(i)** is not the correct value for the specific latent heat.
State and explain whether your value in **(i)** is greater or smaller than the correct value.

.....

.....

..... [2]

## Q6.

**3** When a liquid is boiling, thermal energy must be supplied in order to maintain a constant temperature.

**(a)** State two processes for which thermal energy is required during boiling.

1. .....

.....

2. .....

.....

[2]

**(b)** A student carries out an experiment to determine the specific latent heat of vaporisation of a liquid.
Some liquid in a beaker is heated electrically as shown in Fig. 3.1.

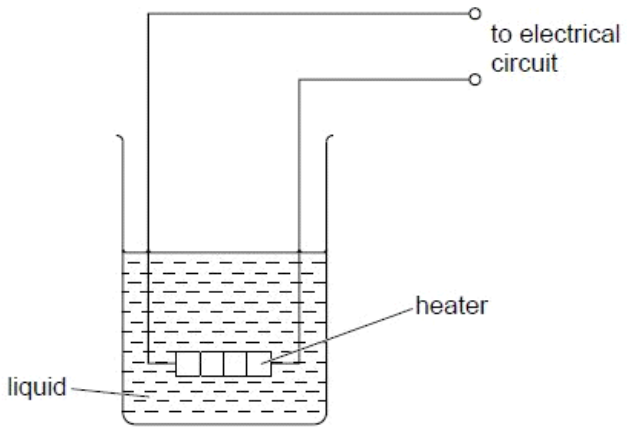



**Fig. 3.1**

Energy is supplied at a constant rate to the heater. When the liquid is boiling at a constant rate, the mass of liquid evaporated in 5.0 minutes is measured.
The power of the heater is then changed and the procedure is repeated.
Data for the two power ratings are given in Fig. 3.2.

| power of heater /W | mass evaporated in 5.0 minutes /g |
|---|---|
| 50.0 | 6.5 |
| 70.0 | 13.6 |

**Fig. 3.2**

**(i)** Suggest

*For Examiner's Use*

**1.** how it may be checked that the liquid is boiling at a constant rate,

.....

..... [1]

**2.** why the rate of evaporation is determined for two different power ratings.

.....

..... [1]

**(ii)** Calculate the specific latent heat of vaporisation of the liquid.

specific latent heat of vaporisation = ..... $J g^{-1}$ [3]

## Q7.

3 **(a)** The resistance of a thermistor at 0 °C is 3840 Ω. At 100 °C the resistance is 190 Ω. When the thermistor is placed in water at a particular constant temperature, its resistance is 2300 Ω.

**(i)** Assuming that the resistance of the thermistor varies linearly with temperature, calculate the temperature of the water.

temperature = ..... °C [2]

**(ii)** The temperature of the water, as measured on the thermodynamic scale of temperature, is 286 K.

By reference to what is meant by the thermodynamic scale of temperature, comment on your answer in **(i)**.

.....

.....

.....

..... [3]

**(b)** A polystyrene cup contains a mass of 95 g of water at 28 °C.

A cube of ice of mass 12 g is put into the water. Initially, the ice is at 0 °C. The water, of specific heat capacity $4.2 \times 10^3$ J kg$^{-1}$ K$^{-1}$, is stirred until all the ice melts.

Assuming that the cup has negligible mass and that there is no heat exchange with the atmosphere, calculate the final temperature of the water.

The specific latent heat of fusion of ice is $3.3 \times 10^5$ J kg$^{-1}$.

temperature = ..... °C [4]

## Q8.

**4** **(a)** The first law of thermodynamics may be expressed in the form

$$\Delta U = q + w.$$

Explain the symbols in this expression.

+ $\Delta U$ .....

+ $q$ .....

+ $w$ .....

[3]

**(b)** **(i)** State what is meant by *specific latent heat*.

.....

.....

.....

..... [3]

**(ii)** Use the first law of thermodynamics to explain why the specific latent heat of vaporisation is greater than the specific latent heat of fusion for a particular substance.

.....

.....

.....

..... [3]

## Q9.

3 **(a)** Define *specific latent heat*.

.....

.....

..... [2]

**(b)** The heater in an electric kettle has a power of 2.40 kW.
When the water in the kettle is boiling at a steady rate, the mass of water evaporated in 2.0 minutes is 106 g.
The specific latent heat of vaporisation of water is 2260 J $g^{-1}$.

Calculate the rate of loss of thermal energy to the surroundings of the kettle during the boiling process.

rate of loss = ..... W [3]

## Q10.

3 **(a)** State what is meant by the *internal energy* of a system.

For Examin Use

.....

.....

.....[2]

**(b)** State and explain qualitatively the change, if any, in the internal energy of the following systems:

**(i)** a lump of ice at 0 °C melts to form liquid water at 0 °C,

.....

.....

.....

.....[3]

**(ii)** a cylinder containing gas at constant volume is in sunlight so that its temperature rises from 25 °C to 35 °C.

.....

.....

.....

.....[3]

## Q11.

1 A kettle is rated as 2.3 kW. A mass of 750 g of water at 20 °C is poured into the kettle. When the kettle is switched on, it takes 2.0 minutes for the water to start boiling. In a further 7.0 minutes, one half of the mass of water is boiled away.

**(a)** Estimate, for this water,

**(i)** the specific heat capacity,

specific heat capacity = ..... $J\,kg^{-1}\,K^{-1}$

(ii) the specific latent heat of vaporisation.

specific latent heat = ..... $J\,kg^{-1}$
[5]

(b) State **one** assumption made in your calculations, and explain whether this will lead to an overestimation or an underestimation of the value for the specific latent heat.

.....

.....

.....[2]

## Q12.

3 The volume of some air, assumed to be an ideal gas, in the cylinder of a car engine is $540\,cm^3$ at a pressure of $1.1\times10^5\,Pa$ and a temperature of 27 °C. The air is suddenly compressed, so that no thermal energy enters or leaves the gas, to a volume of $30\,cm^3$. The pressure rises to $6.5\times10^6\,Pa$.

(a) Determine the temperature of the gas after the compression.

temperature = ..... K [3]

(b) (i) State and explain the first law of thermodynamics.

.....

.....

.....

..... [2]

**(ii)** Use the law to explain why the temperature of the air changed during the compression.

.....

.....

.....

.....

.....[4]

## Q13.

**7** The e.m.f. generated in a thermocouple thermometer may be used for the measurement of temperature.

Fig. 7.1 shows the variation with temperature $T$ of the e.m.f. $E$.

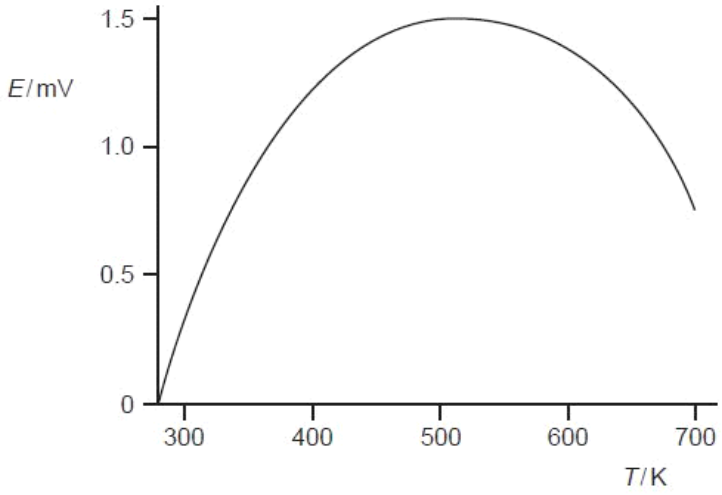



**Fig. 7.1**

**(a)** By reference to Fig. 7.1, state two disadvantages of using this thermocouple when the e.m.f. is about 1.0 mV.

1. .....

2. .....[2]

**(b)** An alternative to the thermocouple thermometer is the resistance thermometer.

State two advantages that a thermocouple thermometer has over a resistance thermometer.

1. .....

.....

2. .....

.....[2]

## Q14.

**3** **(a)** State the first law of thermodynamics in terms of the increase in internal energy $\Delta U$, the heating $q$ of the system and the work $w$ done on the system.

.....

..... [1]

**(b)** The volume occupied by 1.00 mol of liquid water at 100 °C is $1.87 \times 10^{-5}\,m^3$. When the water is vaporised at an atmospheric pressure of $1.03 \times 10^5$ Pa, the water vapour has a volume of $2.96 \times 10^{-2}\,m^3$.
The latent heat required to vaporise 1.00 mol of water at 100 °C and $1.03 \times 10^5$ Pa is $4.05 \times 10^4$ J.
Determine, for this change of state,

**(i)** the work $w$ done on the system,

$w$ = ..... J [2]

**(ii)** the heating $q$ of the system,

$q$ = ..... J [1]

**(iii)** the increase in internal energy $\Delta U$ of the system.

$\Delta U$ = ..... J [1]

**(c)** Using your answer to **(b)(iii)**, estimate the binding energy per molecule in liquid water.

energy = ..... J [2]

## Q15.

**2** A mercury-in-glass thermometer is to be used to measure the temperature of some oil.

The oil has mass 32.0 g and specific heat capacity 1.40 $J\,g^{-1}K^{-1}$. The actual temperature of the oil is 54.0 °C.

The bulb of the thermometer has mass 12.0 g and an average specific heat capacity of 0.180 $J\,g^{-1}K^{-1}$. Before immersing the bulb in the oil, the thermometer reads 19.0 °C.

The thermometer bulb is placed in the oil and the steady reading on the thermometer is taken.

**(a)** Determine

**(i)** the steady temperature recorded on the thermometer,

temperature = ..... °C [3]

**(ii)** the ratio

$$\frac{\text{change in temperature of oil}}{\text{initial temperature of oil}}.$$

ratio = ..... [1]

**(b)** Suggest, with an explanation, a type of thermometer that would be likely to give a smaller value for the ratio calculated in **(a)(ii)**.

.....

.....

..... [2]

**(c)** The mercury-in-glass thermometer is used to measure the boiling point of a liquid. Suggest why the measured value of the boiling point will **not** be affected by the thermal energy absorbed by the thermometer bulb.

.....

.....

.....

..... [2]

## Q16.

**2** **(a)** Define *specific latent heat of fusion*.

*For Examiner Use*

.....

.....

..... [2]

**(b)** Some crushed ice at 0 °C is placed in a funnel together with an electric heater, as shown in Fig. 2.1.

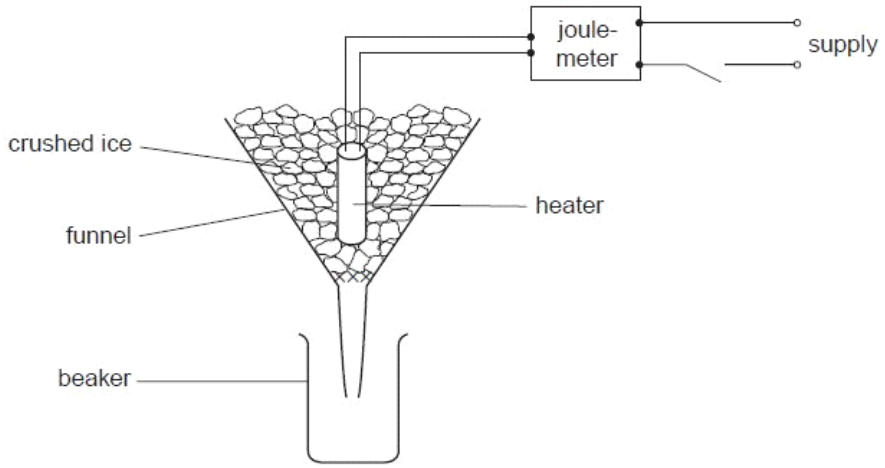



**Fig. 2.1**

The mass of water collected in the beaker in a measured interval of time is determined with the heater switched off. The mass is then found with the heater switched on. The energy supplied to the heater is also measured.
For both measurements of the mass, water is not collected until melting occurs at a constant rate.
The data shown in Fig. 2.2 are obtained.

| | mass of water / g | energy supplied to heater / J | time interval / min |
|---|---|---|---|
| heater switched off | 16.6 | 0 | 10.0 |
| heater switched on | 64.7 | 18000 | 5.0 |

**Fig. 2.2**

**(i)** State why the mass of water is determined with the heater switched off.

.....

..... [1]

**(ii)** Suggest how it can be determined that the ice is melting at a constant rate.

*For Examiner Use*

.....

..... [1]

**(iii)** Calculate a value for the specific latent heat of fusion of ice.

latent heat = ..... kJ $kg^{-1}$ [3]

## Q17.

4 **(a)** Write down an equation to represent the first law of thermodynamics in terms of the heating $q$ of a system, the work $w$ done on the system and the increase $\Delta U$ in the internal energy.

For Examir Use

.....[1]

**(b)** The pressure of an ideal gas is decreased at constant temperature.
Explain what change, if any, occurs in the internal energy of the gas.

.....

.....

.....

.....[3]

## Q18.

3 **(a)** A student states, quite wrongly, that temperature measures the amount of thermal energy (heat) in a body.

For Examine Use

State and explain two observations that show why this statement is incorrect.

1. .....

.....

.....

2. .....

.....

.....

[4]

**(b)** A thermometer and an electrical heater are inserted into holes in an aluminium block of mass 960 g, as shown in Fig. 3.1.

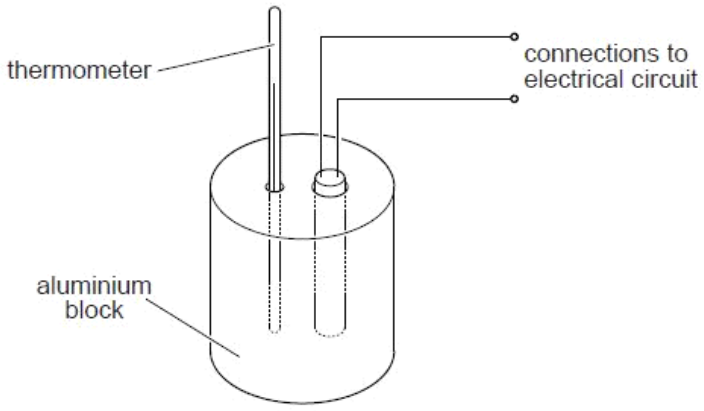



**Fig. 3.1**

The power rating of the heater is 54 W.

*For Examiner's Use*

The heater is switched on and readings of the temperature of the block are taken at regular time intervals. When the block reaches a constant temperature, the heater is switched off and then further temperature readings are taken. The variation with time $t$ of the temperature $\theta$ of the block is shown in Fig. 3.2.

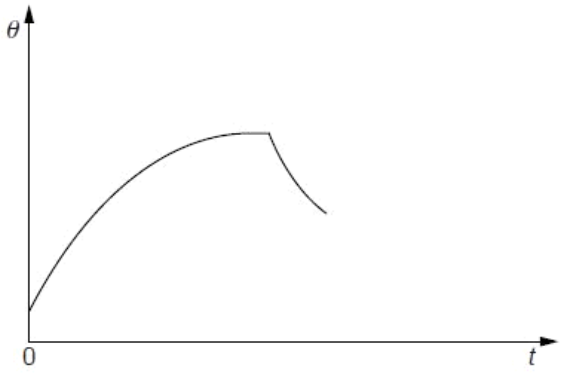



**Fig. 3.2**

**(i)** Suggest why the rate of rise of temperature of the block decreases to zero.

.....

.....

..... [2]

**(ii)** After the heater has been switched off, the maximum rate of fall of temperature is 3.7 K per minute.

Estimate the specific heat capacity of aluminium.

specific heat capacity = ..... J $kg^{-1} K^{-1}$ [3]

## Q19.

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

*For Examiner's Use*

.....

.....

..... [2]

**(b)** The first law of thermodynamics may be represented by the equation

$$\Delta U = q + w.$$

State what is meant by each of the following symbols.

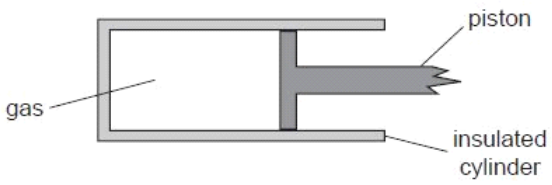
$+\Delta U$ .....

$+q$ .....

$+w$ .....

[3]

**(c)** An amount of 0.18 mol of an ideal gas is held in an insulated cylinder fitted with a piston, as shown in Fig. 2.1.



Atmospheric pressure is $1.0 \times 10^5$ Pa.

The volume of the gas is suddenly increased from $1.8 \times 10^3$ cm$^3$ to $2.1 \times 10^3$ cm$^3$.

For the expansion of the gas,

**(i)** calculate the work done by the gas and hence show that the internal energy changes by 30 J,

[3]

**(ii)** determine the temperature change of the gas and state whether the change is an increase or a decrease.

*For Examiner Use*

change = ..... K

.....

[3]

## Q20.

2 **(a)** A resistance thermometer and a thermocouple thermometer are both used at the same time to measure the temperature of a water bath.

*For Examiner's Use*

Explain why, although both thermometers have been calibrated correctly and are at equilibrium, they may record different temperatures.

.....

.....

..... [2]

**(b)** State

**(i)** in what way the absolute scale of temperature differs from other temperature scales,

.....

..... [1]

**(ii)** what is meant by the absolute zero of temperature.

.....

..... [1]

**(c)** The temperature of a water bath increases from 50.00 °C to 80.00 °C.
Determine, in kelvin and to an appropriate number of significant figures,

**(i)** the temperature 50.00 °C,

temperature = ..... K [1]

**(ii)** the change in temperature of the water bath.

temperature change = ..... K [1]

## Q21.

3 **(a)** Two metal spheres are in thermal equilibrium.
State and explain what is meant by *thermal equilibrium*.

For Examiner's Use

.....

.....

.....[2]

**(b)** An electric water heater contains a tube through which water flows at a constant rate.
The water in the tube passes over a heating coil, as shown in Fig. 3.1.

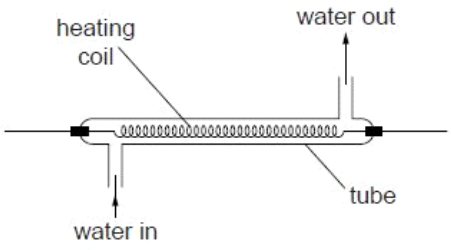



**Fig. 3.1**

The water flows into the tube at a temperature of 18 °C. When the power of the heater is 3.8 kW, the temperature of the water at the outlet is 42 °C.
The specific heat capacity of water is $4.2\,J\,g^{-1}\,K^{-1}$.

**(i)** Use the data to calculate the flow rate, in $g\,s^{-1}$, of water through the tube.

flow rate = ..... $g\,s^{-1}$ [3]

**(ii)** State and explain whether your answer in **(i)** is likely to be an overestimate or an underestimate of the flow rate.

.....

.....

.....[2]

## Q22.

3 The volume of 1.00 kg of water in the liquid state at 100 °C is $1.00 \times 10^{-3}$ m$^3$. The volume of 1.00 kg of water vapour at 100 °C and atmospheric pressure $1.01 \times 10^5$ Pa is 1.69 m$^3$.

**(a)** Show that the work done against the atmosphere when 1.00 kg of liquid water becomes water vapour is $1.71 \times 10^5$ J.

[2]

**(b) (i)** The first law of thermodynamics may be given by the expression

$$\Delta U = +q + w$$

where $\Delta U$ is the increase in internal energy of the system.

State what is meant by

**1.** $+q$,

..... [1]

**2.** $+w$.

..... [1]

**(ii)** The specific latent heat of vaporisation of water at 100 °C is $2.26 \times 10^6$ J kg$^{-1}$.

A mass of 1.00 kg of liquid water becomes water vapour at 100 °C.

Determine, using your answer in **(a)**, the increase in internal energy of this mass of water during vaporisation.

increase in internal energy = ..... J [2]

## Q23.

3 A microwave cooker uses electromagnetic waves of frequency 2450 MHz.
The microwaves warm the food in the cooker by causing water molecules in the food to oscillate with a large amplitude at the frequency of the microwaves.

**(a)** State the name given to this phenomenon.

..... [1]

**(b)** The effective microwave power of the cooker is 750 W.
The temperature of a mass of 280 g of water rises from 25 °C to 98 °C in a time of 2.0 minutes.

Calculate a value for the specific heat capacity of the water.

specific heat capacity = ..... $J\,kg^{-1}\,K^{-1}$ [3]

**(c)** The value of the specific heat capacity determined from the data in **(b)** is greater than the accepted value.
A student gives as the reason for this difference: 'heat lost to the surroundings'.

Suggest, in more detail than that given by the student, a possible reason for the difference.

.....

..... [1]

## Q24.

3 A fixed mass of gas has an initial volume of $5.00 \times 10^{-4}\,m^3$ at a pressure of $2.40 \times 10^5\,Pa$ and a temperature of 288 K. It is heated at constant pressure so that, in its final state, the volume is $14.5 \times 10^{-4}\,m^3$ at a temperature of 835 K, as illustrated in Fig. 3.1.

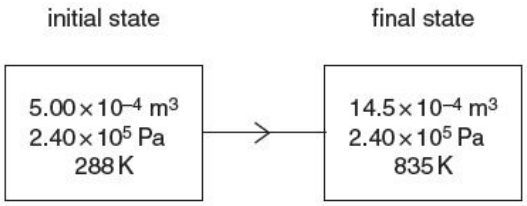



Fig. 3.1

**(a)** Show that these two states provide evidence that the gas behaves as an ideal gas.

[3]

**(b)** The total thermal energy supplied to the gas for this change is 569 J.

Determine

**(i)** the external work done,

work done = ..... J [2]

(ii) the change in internal energy of the gas. State whether the change is an increase or a decrease in internal energy.

change in internal energy = ..... J

..... [2]

**Thermal Properties - 2020 A2**

**1.** June/2020/Paper_42/No.3

By reference to the first law of thermodynamics, state and explain the change, if any, in the internal energy of:

**(a)** a lump of solid lead as it melts at constant temperature

.....

.....

.....

.....

..... [3]

**(b)** some gas in a toy balloon when the balloon bursts and no thermal energy enters or leaves the gas.

.....

.....

.....

.....

..... [3]

[Total: 6]



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**Thermal Properties - 2021 A2**

**1.** Nov/2021/Paper_41/No.3

**(a)** Define *specific heat capacity*.

.....

.....

..... [2]

**(b)** A sealed container of fixed volume $V$ contains $N$ molecules, each of mass $m$, of an ideal gas at pressure $p$.

**(i)** State an expression, in terms of $V$, $N$, $p$ and the Boltzmann constant $k$, for the thermodynamic temperature $T$ of the gas.

..... [1]

**(ii)** Show that the mean translational kinetic energy $E_K$ of a molecule of the gas is given by

$$E_K = \frac{3}{2}kT.$$

[2]

**(iii)** Explain why the internal energy of the gas is equal to the total kinetic energy of the molecules.

.....

.....

..... [2]

**(c)** The gas in **(b)** is supplied with thermal energy $Q$.

**(i)** Explain, with reference to the first law of thermodynamics, why the increase in internal energy of the gas is $Q$.

.....

.....

..... [2]



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**(ii)** Use the expression in **(b)(ii)** and the information in **(c)(i)** to show that the specific heat capacity $c$ of the gas is given by

$$c = \frac{3k}{2m}.$$

[2]

**(d)** The container in **(b)** is now replaced with one that does not have a fixed volume. Instead, the gas is able to expand, so that the pressure of the gas remains constant as thermal energy is supplied.

Suggest, with a reason, how the specific heat capacity of the gas would now compare with the value in **(c)(ii)**.

.....

.....

.....

..... [2]

[Total: 13]



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**2.** March/2021/Paper_42/No.3

**(a)** Using a simple kinetic model of matter, describe the structure of a solid.

.....

.....

..... [2]

**(b)** The specific latent heat of vaporisation is much greater than the specific latent heat of fusion for the same substance.
Explain this, in terms of the spacing of molecules.

.....

.....

..... [1]

**(c)** A heater supplies energy at a constant rate to 0.045 kg of a substance. The variation with time of the temperature of the substance is shown in Fig. 3.1. The substance is perfectly insulated from its surroundings.

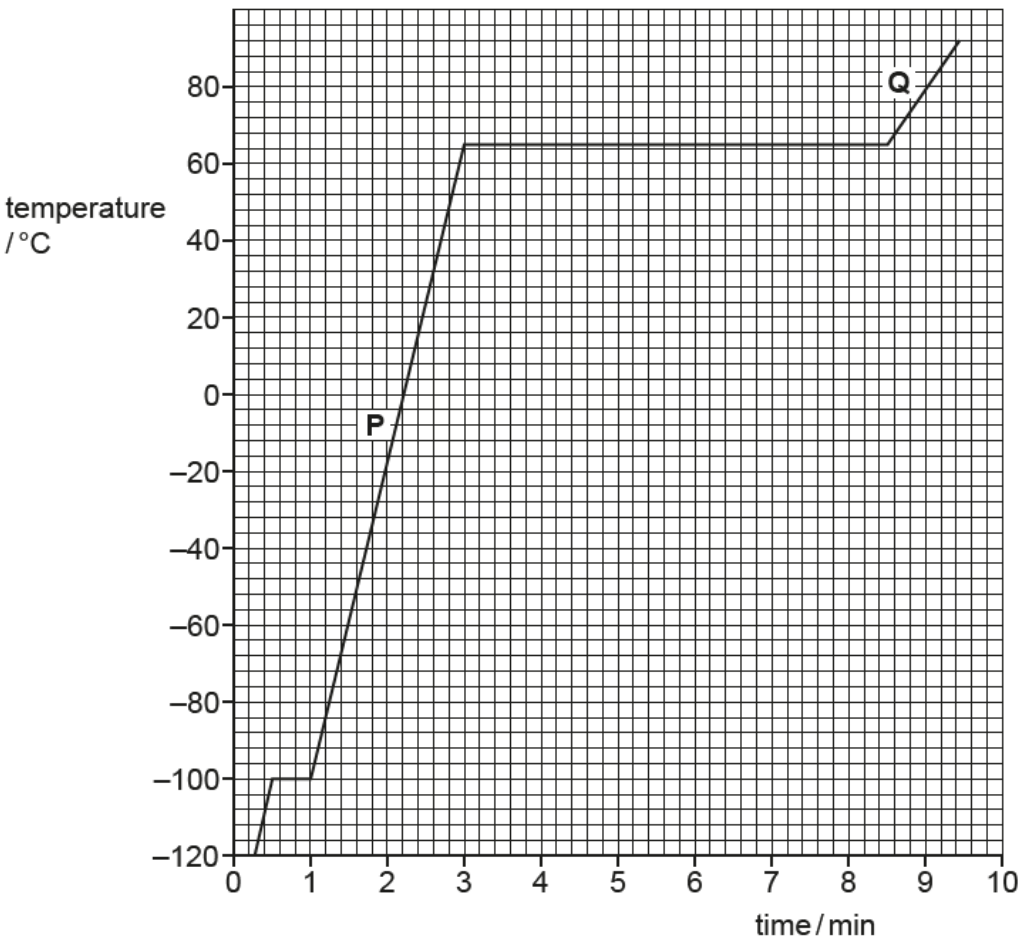



**Fig. 3.1**



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**(i)** Determine the temperature at which the substance melts.

temperature = ..... °C [1]

**(ii)** The power of the heater is 150 W.
Use data from Fig. 3.1 to calculate, in $kJ\,kg^{-1}$, the specific latent heat of vaporisation $L$ of the substance.

$L$ = ..... $kJ\,kg^{-1}$ [3]

**(iii)** Suggest what can be deduced from the fact that section **Q** on the graph is less steep than section **P**.

.....

..... [1]

[Total: 8]



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**1.** Nov/2023/Paper_9702/41/No.2

**(a)** Define specific heat capacity.

.....

.....

..... [2]

**(b)** An ideal gas of mass 0.35 kg is heated at a constant pressure of $2.0 \times 10^5$ Pa so that its internal energy increases by 7600 J. During this process, the volume of the gas increases from 0.038 $m^3$ to 0.063 $m^3$ and the temperature increases by 56 °C.

**(i)** Show that the magnitude of the work done on the gas is 5000 J.

[1]

**(ii)** Explain whether the work done on the gas is positive or negative.

.....

.....

..... [2]

**(iii)** Determine the magnitude of the thermal energy $q$ transferred to the gas.

$q$ = ..... J [2]



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**(iv)** Calculate the specific heat capacity of the gas for this process. Give a unit with your answer.

specific heat capacity = ..... unit ..... [2]

**(c)** The gas in **(b)** is now heated at constant volume rather than at constant pressure.
The increase in internal energy of the gas is the same as in **(b)**.

Use the first law of thermodynamics to explain whether the specific heat capacity of the gas for this process is less than, the same as, or greater than the answer in **(b)(iv)**.

.....

.....

.....

.....

..... [3]

[Total: 12]



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**2.** Nov/2023/Paper_9702/42/No.3

**(a)** State what is meant by the internal energy of a system.

.....

.....

..... [2]

**(b)** Use the first law of thermodynamics to explain what happens to the internal energy:

**(i)** of a spring when it is stretched at constant temperature within its elastic limit

.....

.....

.....

.....

..... [3]

**(ii)** of a sample of water when it evaporates from a rain puddle on a hot day.

.....

.....

.....

.....

..... [3]

[Total: 8]



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**3.** June/2023/Paper_9702/41/No.4b(ii , iii)

**(b)** An ideal gas has amount of substance $n$.
The gas is initially in state X, with pressure $2p$ and volume $V$.
The gas is cooled at constant volume to state Y, with pressure $p$.
The gas is then heated at constant pressure to state Z, with volume $2V$.
Finally, the gas returns at constant temperature to state X.

**(ii)** On Fig. 4.1, sketch the variation with volume of pressure for the gas as the gas undergoes the three changes. The state X is labelled. Label states Y and Z.

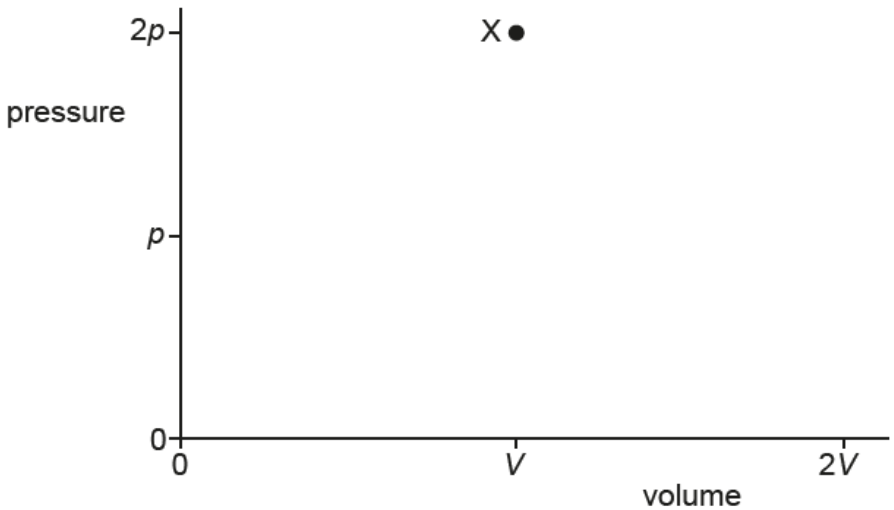



**Fig. 4.1**

[3]



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**(iii)** During the change of state from Y to Z, the increase in internal energy of the gas is $U$. During the change of state from Z to X, the work done on the gas is $W$.

Complete Table 4.1 to indicate, for each of the three changes of state, the increase in internal energy of the gas, the thermal energy transferred to the gas and the work done on the gas, in terms of $p$, $V$, $U$ and $W$.

**Table 4.1**

| change | increase in internal energy of gas | thermal energy transferred to gas | work done on gas |
|---|---|---|---|
| X to Y | | | |
| Y to Z | $+U$ | | |
| Z to X | | | $+W$ |

[5]



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**4.** June/2023/Paper_9702/42/No.3

**(a)** State the first law of thermodynamics. Identify the meaning of any symbols that you use.

.....

.....

..... [2]

**(b)** The state of an ideal gas is continuously changed according to the cycle ABCDA shown in Fig. 3.1.

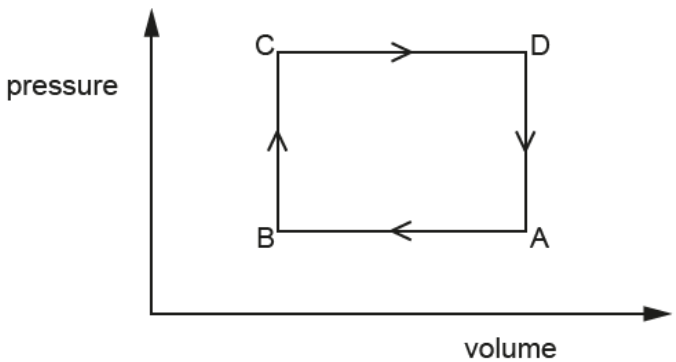



**Fig. 3.1**

**(i)** Complete Table 3.1 for the changes A to B and B to C by placing two ticks (✓) in each row.

**Table 3.1**

| change | change in internal energy | | | work done on gas | | |
|---|---|---|---|---|---|---|
| | decrease | no change | increase | negative | zero | positive |
| A to B | | | | | | |
| B to C | | | | | | |

[4]



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**(ii)** Use the first law of thermodynamics to describe and explain the energy transfers associated with one complete cycle ABCDA.

.....

.....

.....

.....

..... [3]

[Total: 9]



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**(b)** A fixed amount of helium gas is sealed in a container. The helium gas has a pressure of $1.10 \times 10^5$ Pa, and a volume of 540 $cm^3$ at a temperature of 27 °C.

The volume of the container is rapidly decreased to 30.0 $cm^3$. The pressure of the helium gas increases to $6.70 \times 10^6$ Pa and its temperature increases to 742 °C, as illustrated in Fig. 2.1.

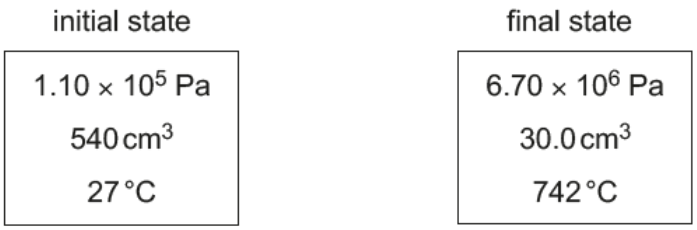



**Fig. 2.1**

No thermal energy enters or leaves the helium gas during this process.

**(ii)** The first law of thermodynamics may be expressed as

$$\Delta U = q + W.$$

Use the first law of thermodynamics to explain why the temperature of the helium gas increases.

.....

.....

.....

.....

..... [2]



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**(iii)** The average translational kinetic energy $E_K$ of a molecule of an ideal gas is given by

$$E_K = \frac{3}{2}kT$$

where $k$ is the Boltzmann constant and $T$ is the thermodynamic temperature.

Calculate the change in the total kinetic energy of the molecules of the helium gas.

change in kinetic energy = ..... J [3]



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