2 A large container of volume $85\,m^3$ is filled with 110 kg of an ideal gas. The pressure of the gas is 1.0×10^5 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:

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

ratio = ... [2]

[Total: 10]

2 **(a)** A square box of volume V contains N molecules of an ideal gas. Each molecule has mass m.

Using the kinetic theory of ideal gases, it can be shown that, if all the molecules are moving with speed v at right angles to one face of the box, the pressure p exerted on the face of the box is given by the expression

$$pV = Nmv^2. \qquad \text{(equation 1)}$$

This expression leads to the formula

$$p = \frac{1}{3}\rho\langle c^2\rangle \qquad \text{(equation 2)}$$

for the pressure p of an ideal gas, where ρ is the density of the gas and $\langle c^2\rangle$ is the mean-square speed of the molecules.

Explain how each of the following terms in equation 2 is derived from equation 1:

ρ: ....

....

$\frac{1}{3}$: ....

....

$\langle c^2\rangle$: ....

....
[4]

(b) An ideal gas has volume, pressure and temperature as shown in Fig. 2.1.

volume $6.0 \times 10^{-3}\,m^3$
pressure $3.0 \times 10^5\,Pa$
temperature 17 °C

Fig. 2.1

The mass of the gas is 20.7 g.

Calculate the mass of one molecule of the gas.

mass = ... g [4]

[Total: 8]

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]

2 **(a)** State what is meant by

(i) the Avogadro constant N_A,

....

.... [1]

(ii) the mole.

....

.... [2]

(b) A container has a volume of $1.8 \times 10^4\,\text{cm}^3$.

The ideal gas in the container has a pressure of $2.0 \times 10^7\,\text{Pa}$ at a temperature of 17 °C.

Show that the amount of gas in the cylinder is 150 mol.

[1]

(c) Gas molecules leak from the container in **(b)** at a constant rate of $1.5 \times 10^{19}\,\text{s}^{-1}$.
The temperature remains at 17 °C.
In a time t, the amount of gas in the container is found to be reduced by 5.0%.

Calculate

(i) the pressure of the gas after the time t,

pressure = ... Pa [2]

(ii) the time t.

t = ... s [3]

[Total: 9]

3 **(a)** Explain what is meant by the statement that two bodies are in *thermal equilibrium*.

....

....

.... [1]

(b) Suggest suitable types of thermometer, one in each case, to measure

(i) the temperature of the flame of a Bunsen burner,

.... [1]

(ii) the change in temperature of a small crystal when it is exposed to a pulse of ultrasound energy.

.... [1]

(c) Some water is heated so that its temperature changes from 26.5 °C to a final temperature of 38.0 °C.

State, to an appropriate number of decimal places,

(i) the change in temperature in kelvin,

change = ... K [1]

(ii) the final temperature in kelvin.

final temperature = ... K [1]

[Total: 5]

2 **(a)** The equation of state for an ideal gas of volume V at pressure p is

$$pV = nRT$$

where R is the molar gas constant.

State what is meant by

(i) the symbol n,

....

....[1]

(ii) the symbol T.

....

....[1]

(b) An ideal gas is held in a container of volume $2.4 \times 10^3\,\text{cm}^3$ at pressure $4.9 \times 10^5\,\text{Pa}$. The temperature of the gas is $100\,°\text{C}$.

Show that the number of molecules of the gas in the container is 2.3×10^{23}.

[3]

(c) Use data from **(b)** to estimate the mean distance between molecules in the gas.

mean distance = ... cm [3]

[Total: 8]

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]

2 **(a)** Use one of the assumptions of the kinetic theory of gases to explain why the potential energy of the molecules of an ideal gas is zero.

....

....[1]

(b) The average translational kinetic energy E_K of a molecule of an ideal gas is given by the expression

$$E_K = \frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

where m is the mass of a molecule and k is the Boltzmann constant.

State the meaning of the symbol

(i) $\langle c^2\rangle$,

....[1]

(ii) T.

....[1]

(c) A cylinder of constant volume $4.7 \times 10^4\,cm^3$ contains an ideal gas at pressure $2.6 \times 10^5\,Pa$ and temperature 173 °C.

The gas is heated. The thermal energy transferred to the gas is 2900 J. The final temperature and pressure of the gas are T and p, as illustrated in Fig. 2.1.

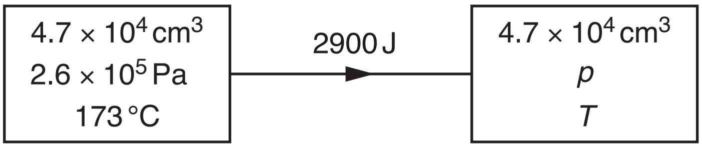

Fig. 2.1

(i) Calculate

1. the number N of molecules in the cylinder,

N = ...[3]

2. the increase in average kinetic energy of a molecule during the heating process.

increase = ... J [1]

(ii) Use your answer in **(i) part 2** to determine the final temperature *T*, in kelvin, of the gas in the cylinder.

T = ... K [3]

[Total: 10]

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.

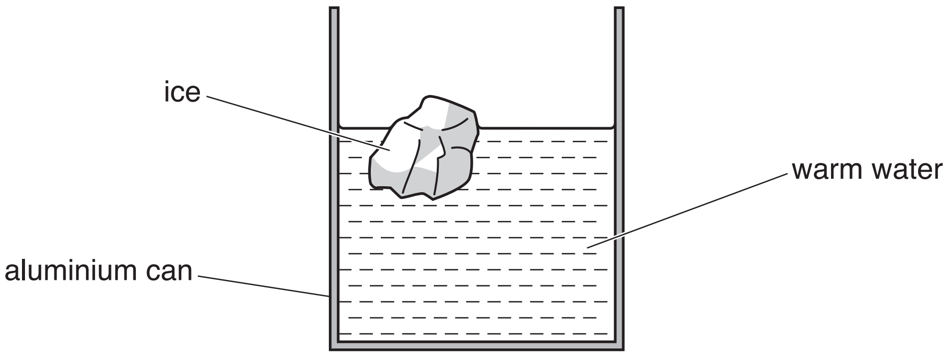

Fig. 3.1

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

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 2.3×10^4 J,

[2]

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

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

[Total: 7]

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.

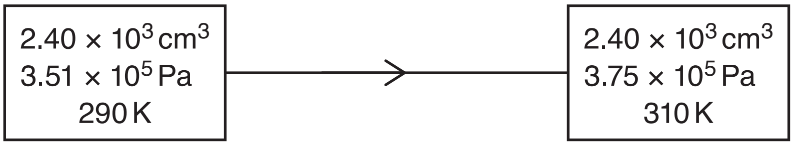

Fig. 2.1

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]

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.

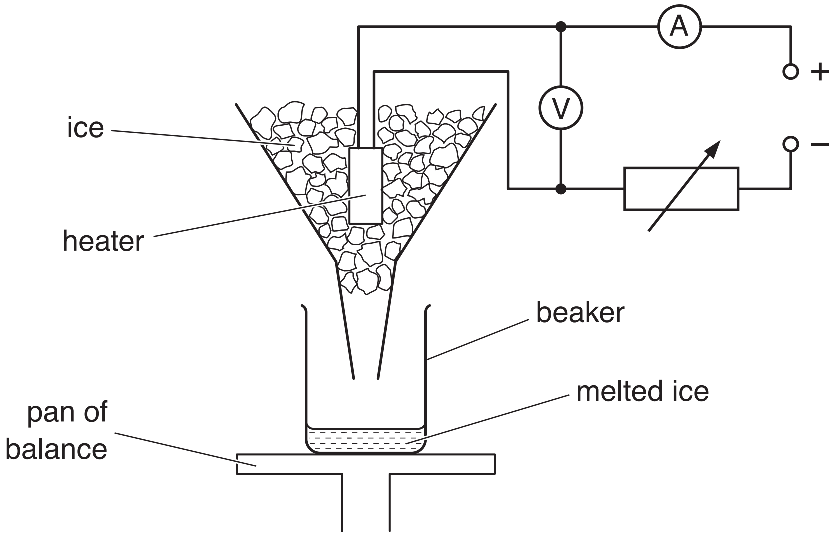

Fig. 3.1

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.

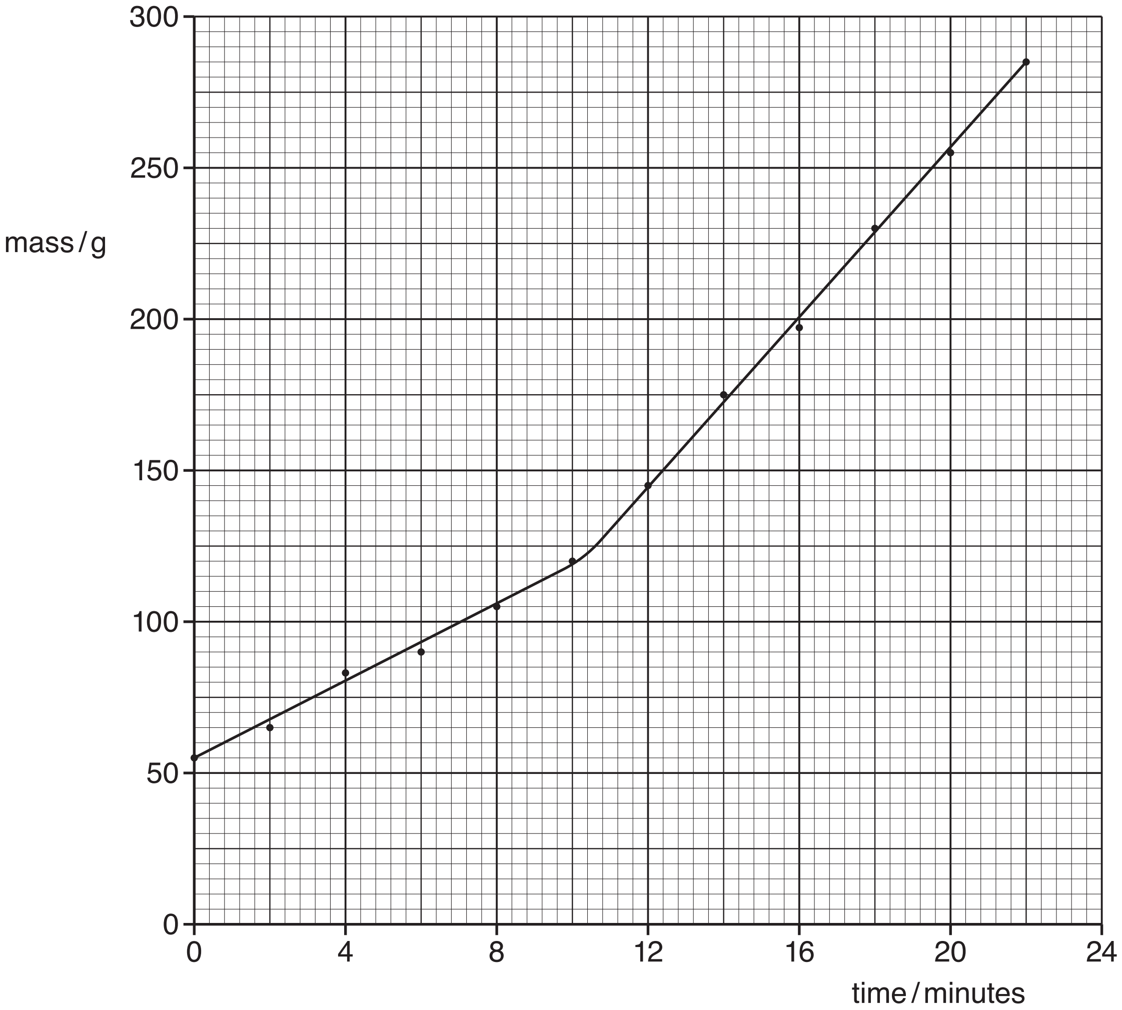

Fig. 3.2

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 after time 10 minutes	1.8 3.6	7.3 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]

2 **(a)** State what is meant by an *ideal gas*.

....

....

....[2]

(b) An ideal gas comprised of single atoms is contained in a cylinder and has a volume of $1.84 \times 10^{-2}\,\mathrm{m}^3$ at a pressure of $2.12 \times 10^{7}\,\mathrm{Pa}$.
The mass of gas in the cylinder is 3.20 kg.

(i) Determine, to three significant figures, the root-mean-square (r.m.s.) speed of the atoms of the gas.

r.m.s. speed = ... $\mathrm{m\,s^{-1}}$ [3]

(ii) The temperature of the gas in the cylinder is 22 °C.

Determine, to three significant figures,

1. the amount, in mol, of the gas,

amount = ... mol [2]

2. the mass of one atom of the gas.

mass = ... kg [2]

(c) Use your answer in **(b)(ii) part 2** to determine the nucleon number *A* of an atom of the gas.

A = ... [1]

[Total: 10]

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.

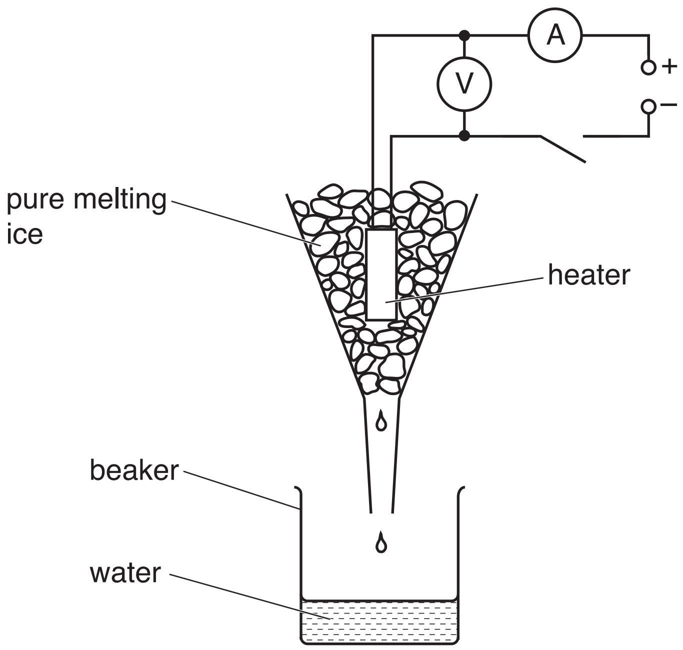

Fig. 3.1

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]

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 ΔU.

....

....[1]

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

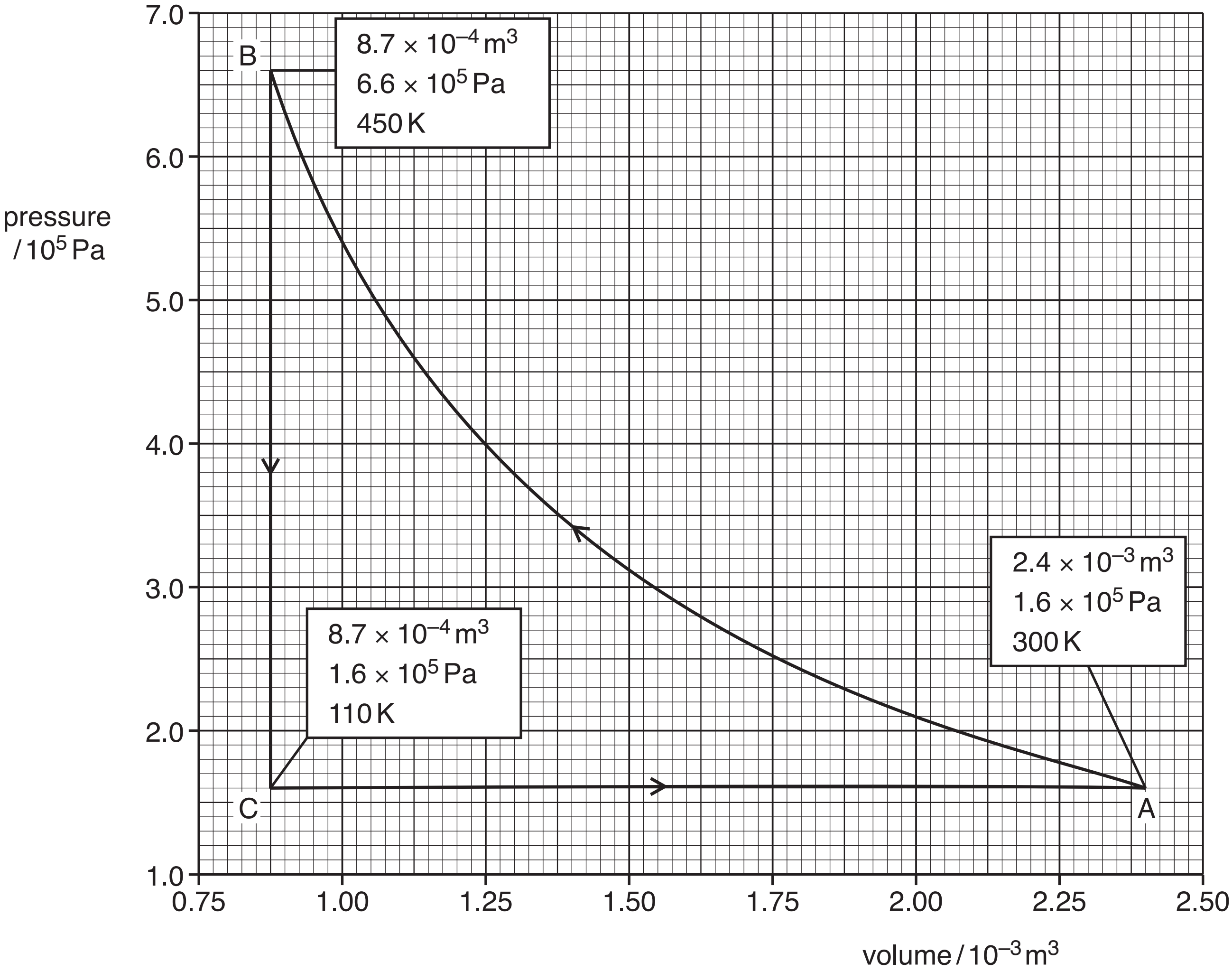

Fig. 2.1

At point A, the gas has volume 2.4×10^{-3} m^3, pressure 1.6×10^5 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 8.7×10^{-4} m^3, pressure 6.6×10^5 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 1.6×10^5 Pa and temperature 110 K.

Finally, the gas is returned to point A.

(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	ΔU / J
A → B	....	....	....
B → C	....	....	....
C → A	....	....	....

Fig. 2.2

[4]

[Total: 11]

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.

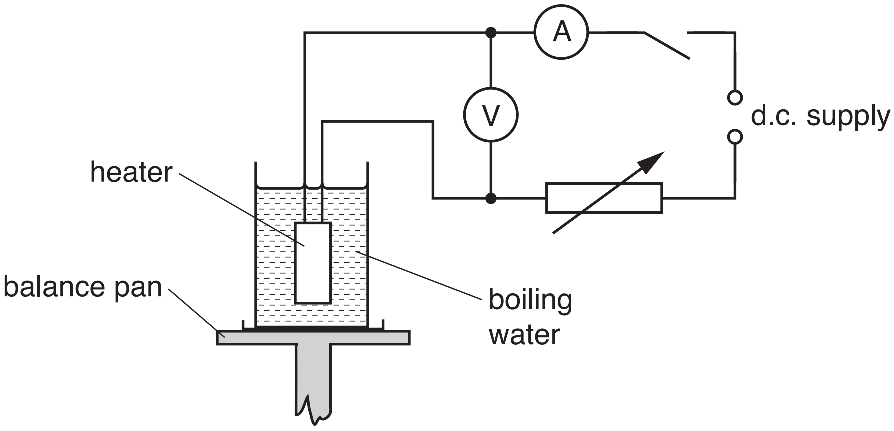

Fig. 2.1

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 14.2	5.2 6.4	5.0 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]

2 **(a)** The pressure p and volume V of an ideal gas are related to the density ρ 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]

2 **(a)** State what is meant by an *ideal* gas.

....

....

....[2]

(b) The mean-square speed of the atoms of a fixed mass of an ideal gas at 32 °C is $1.9 \times 10^6\, m^2 s^{-2}$.

The gas is heated at constant volume to a temperature of 80 °C.

Determine

(i) the rise, in kelvin, of the temperature of the gas,

temperature rise = ... K [1]

(ii) the root-mean-square (r.m.s.) speed of the atoms at 80 °C.

r.m.s. speed = ... $m\,s^{-1}$ [3]

3 **(a)** State an expression, in terms of work done and heating, that is used to calculate the increase in internal energy of a system.

....

....

....[2]

(b) State and explain, in terms of your expression in **(a)**, the change, if any, in the internal energy

(i) of the water in an ice cube when the ice melts, at atmospheric pressure, to form a liquid without any change of temperature,

....

....

....

....[3]

(ii) of the gas in a tyre when the tyre bursts so that the gas suddenly increases in volume. Assume that the gas is ideal.

....

....

....

....[3]

2 In a sample of gas at room temperature, five atoms have the following speeds:

$$1.32 \times 10^3\,\mathrm{m\,s^{-1}}$$
$$1.50 \times 10^3\,\mathrm{m\,s^{-1}}$$
$$1.46 \times 10^3\,\mathrm{m\,s^{-1}}$$
$$1.28 \times 10^3\,\mathrm{m\,s^{-1}}$$
$$1.64 \times 10^3\,\mathrm{m\,s^{-1}}.$$

For these five atoms, calculate, to three significant figures,

(a) the mean speed,

mean speed = ... $\mathrm{m\,s^{-1}}$ [1]

(b) the mean-square speed,

mean-square speed = ... $\mathrm{m^2\,s^{-2}}$ [2]

(c) the root-mean-square speed.

root-mean-square speed = ... $\mathrm{m\,s^{-1}}$ [1]

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

....

....

....[2]

(b) A beaker containing a liquid is placed on a balance, as shown in Fig. 3.1.

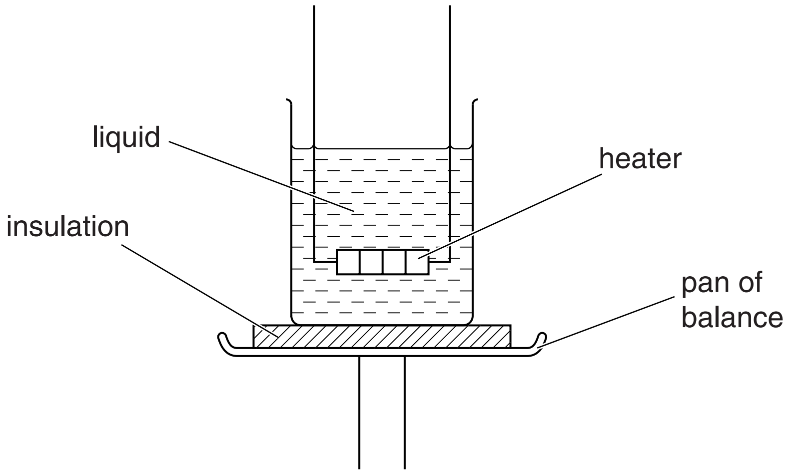

Fig. 3.1

A heater of power 110W is immersed in the liquid. The heater is switched on and, when the liquid is boiling, balance readings m are taken at corresponding times t.

A graph of the variation with time t of the balance reading m is shown in Fig. 3.2.

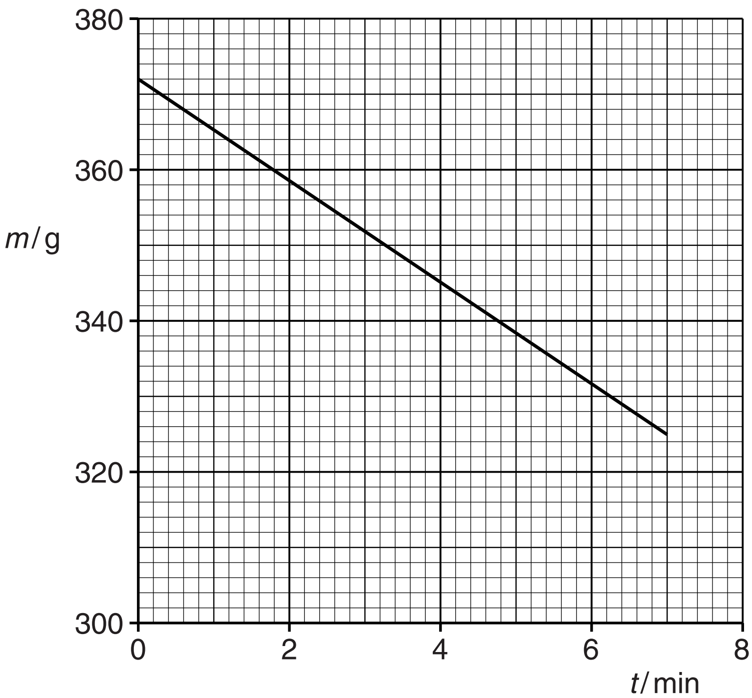

Fig. 3.2

(i) State the feature of Fig. 3.2 which suggests that the liquid is boiling at a steady rate.

....

....[1]

(ii) Use data from Fig. 3.2 to determine a value for the specific latent heat *L* of vaporisation of the liquid.

L = ... J kg^{-1} [3]

(iii) State, with a reason, whether the value determined in **(ii)** is likely to be an overestimate or an underestimate of the normally accepted value for the specific latent heat of vaporisation of the liquid.

....

....

....[2]