For Examiner's Use

1 **(a)** **(i)** The kinetic theory of gases leads to the equation

$$\frac{1}{2}m<c^2> = \frac{3}{2}kT.$$

Explain the significance of the quantity $\frac{1}{2}m<c^2>$.

....

....

(ii) Use the equation to suggest what is meant by the absolute zero of temperature.

....

....

[3]

(b) Two insulated gas cylinders **A** and **B** are connected by a tube of negligible volume, as shown in Fig. 3.1.

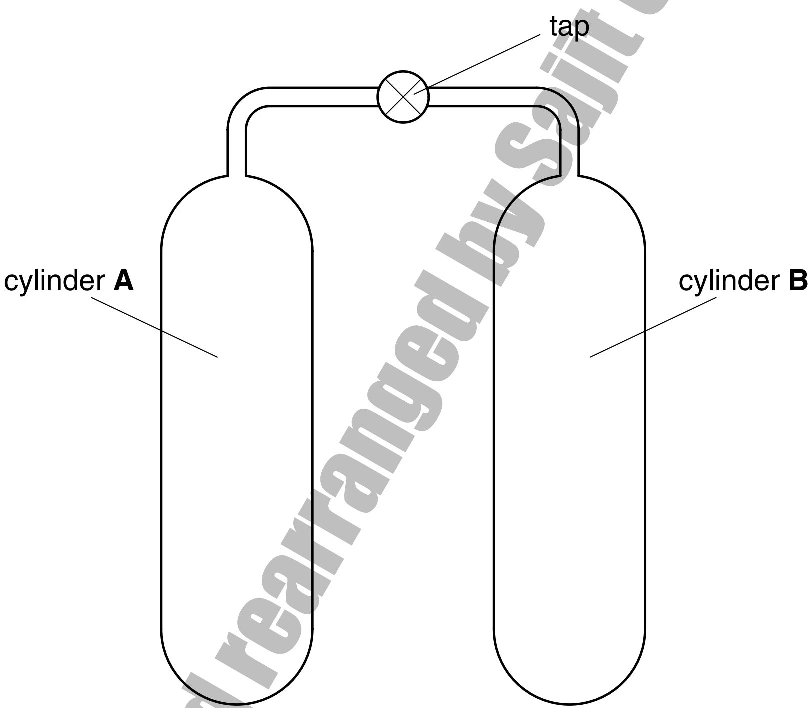

Fig. 3.1

For Examiner's Use

Each cylinder has an internal volume of 2.0×10^{-2} m^3. Initially, the tap is closed and cylinder **A** contains 1.2 mol of an ideal gas at a temperature of 37 °C. Cylinder **B** contains the same ideal gas at pressure 1.2×10^5 Pa and temperature 37 °C.

(i) Calculate the amount, in mol, of the gas in cylinder **B**.

amount = ... mol

(ii) The tap is opened and some gas flows from cylinder **A** to cylinder **B**. Using the fact that the total amount of gas is constant, determine the final pressure of the gas in the cylinders.

pressure = ... Pa

[6]

2 The pressure p of an ideal gas is given by the expression

$$p = \frac{1}{3}\frac{Nm}{V}<c^2>.$$

(a) Explain the meaning of the symbol $<c^2>$.

....

.... [2]

(b) The ideal gas has a density of $2.4\,\text{kg}\,\text{m}^{-3}$ at a pressure of 2.0×10^5 Pa and a temperature of 300 K.

(i) Determine the root-mean-square (r.m.s.) speed of the gas atoms at 300 K.

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

(ii) Calculate the temperature of the gas for the atoms to have an r.m.s. speed that is twice that calculated in **(i)**.

temperature = ... K [3]

For Examiner's Use

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

....

....

....[2]

(b) The product of pressure p and volume V of an ideal gas of density ρ at temperature T is given by the expressions

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

and

$$pV = NkT,$$

where N is the number of molecules and k is the Boltzmann constant.

(i) State the meaning of the symbol $\langle c^2\rangle$.

....[1]

(ii) Deduce that the mean kinetic energy E_K of the molecules of an ideal gas is given by the expression

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

[2]

(c) In order for an atom to escape completely from the Earth's gravitational field, it must have a speed of approximately $1.1 \times 10^4\,\mathrm{m\,s^{-1}}$ at the top of the Earth's atmosphere.

(i) Estimate the temperature at the top of the atmosphere such that helium, assumed to be an ideal gas, could escape from the Earth. The mass of a helium atom is 6.6×10^{-27} kg.

temperature = ... K [2]

(ii) Suggest why some helium atoms will escape at temperatures below that calculated in **(i)**.

....

....[1]

4 **(a)** The equation

$$pV = constant \times T$$

relates the pressure p and volume V of a gas to its kelvin (thermodynamic) temperature T.

State two conditions for the equation to be valid.

1. ....

....

2. ....

.... [2]

(b) A gas cylinder contains $4.00 \times 10^4\,\text{cm}^3$ of hydrogen at a pressure of $2.50 \times 10^7\,\text{Pa}$ and a temperature of 290 K.

The cylinder is to be used to fill balloons. Each balloon, when filled, contains $7.24 \times 10^3\,\text{cm}^3$ of hydrogen at a pressure of $1.85 \times 10^5\,\text{Pa}$ and a temperature of 290 K.

Calculate, assuming that the hydrogen obeys the equation in **(a)**,

(i) the total amount of hydrogen in the cylinder,

amount = ……………………….. mol [3]

(ii) the number of balloons that can be filled from the cylinder.

number = ……………………….. [3]

5 **(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.

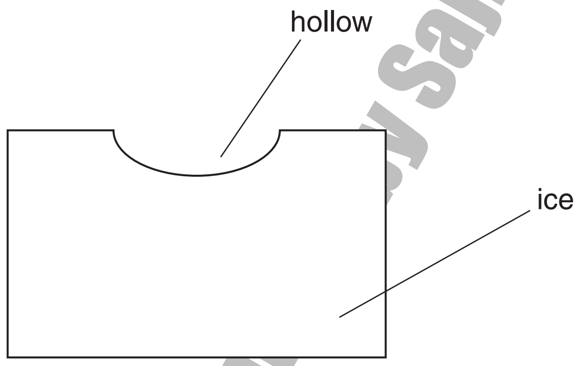

Fig. 2.1

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]

6 **(a)** Explain qualitatively how molecular movement causes the pressure exerted by a gas.

....

....

....

....[3]

(b) The density of neon gas at a temperature of 273 K and a pressure of 1.02×10^5 Pa is 0.900 kg m^{-3}. Neon may be assumed to be an ideal gas.

Calculate the root-mean-square (r.m.s.) speed of neon atoms at

(i) 273 K,

speed = ... m s^{-1} [3]

(ii) 546 K.

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

(c) The calculations in **(b)** are based on the density for neon being 0.900 kg m^{-3}.
Suggest the effect, if any, on the root-mean-square speed of changing the density at constant temperature.

....

....

....[2]

7 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.

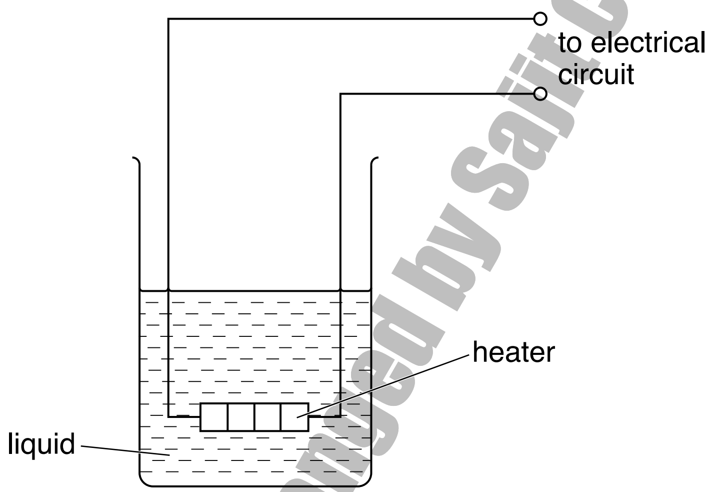

Fig. 3.1

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

For Examiner's Use

(i) Suggest

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]

7 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]

8 The air in a car tyre has a constant volume of $3.1 \times 10^{-2}\,m^3$. The pressure of this air is $2.9 \times 10^5\,Pa$ at a temperature of 17 °C. The air may be considered to be an ideal gas.

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

....

....

.... [2]

(b) Calculate the amount of air, in mol, in the tyre.

amount = ……………………………. mol [2]

(c) The pressure in the tyre is to be increased using a pump. On each stroke of the pump, 0.012 mol of air is forced into the tyre.
Calculate the number of strokes of the pump required to increase the pressure to $3.4 \times 10^5\,Pa$ at a temperature of 27 °C.

number = ……………………………. [3]

9 **(a)** An amount of 1.00 mol of Helium-4 gas is contained in a cylinder at a pressure of 1.02×10^5 Pa and a temperature of 27 °C.

(i) Calculate the volume of gas in the cylinder.

volume = ... m^3 [2]

(ii) Hence show that the average separation of gas atoms in the cylinder is approximately 3.4×10^{-9} m.

[2]

(b) Calculate

(i) the gravitational force between two Helium-4 atoms that are separated by a distance of 3.4×10^{-9} m,

force = ... N [3]

(ii) the ratio

$$\frac{\text{weight of a Helium-4 atom}}{\text{gravitational force between two Helium-4 atoms with separation } 3.4 \times 10^{-9}\,\text{m}}.$$

ratio = ...[2]

(c) Comment on your answer to **(b)(ii)** with reference to one of the assumptions of the kinetic theory of gases.

....

....

....[2]

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

....

....

.... [2]

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

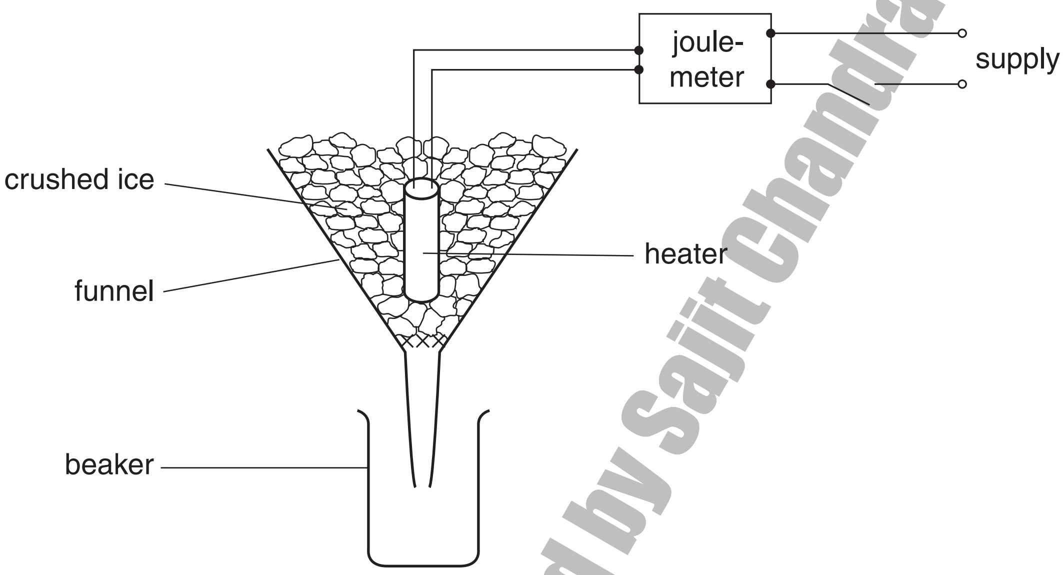

Fig. 2.1

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 heater switched on	16.6 64.7	0 18000	10.0 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.

....

....[1]

For Examiner's Use

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

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

11 An ideal gas occupies a container of volume $4.5 \times 10^3\,cm^3$ at a pressure of $2.5 \times 10^5\,Pa$ and a temperature of 290 K.

For Examiner's Use

(a) Show that the number of atoms of gas in the container is 2.8×10^{23}.

[2]

(b) Atoms of a real gas each have a diameter of $1.2 \times 10^{-10}\,m$.

(i) Estimate the volume occupied by 2.8×10^{23} atoms of this gas.

volume = ... m^3 [2]

(ii) By reference to your answer in **(i)**, suggest whether the real gas does approximate to an ideal gas.

....

....

.... [2]

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

....

....

.... [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.

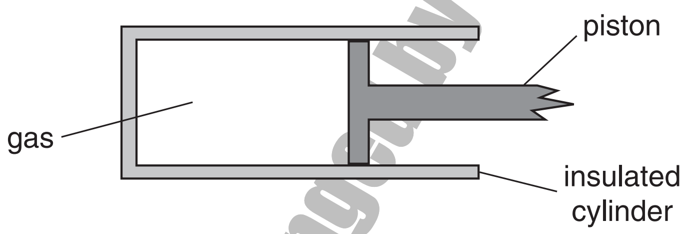

Fig. 2.1

Atmospheric pressure is 1.0×10^5 Pa.

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

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]

For Examiner's Use

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

change = ... K

....
[3]

13 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*.

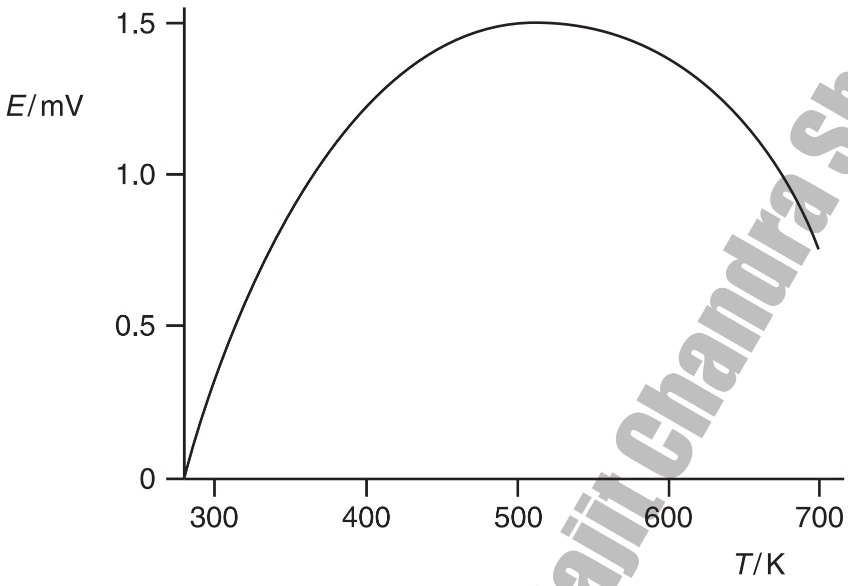

Fig. 7.1

(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]

14 **(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.

For Examiner's Use

(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 $4.2 \times 10^3\,\text{J kg}^{-1}\,\text{K}^{-1}$, 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 $3.3 \times 10^5\,\text{J kg}^{-1}$.

temperature = ... °C [4]

For Examiner's Use

14 **(a)** Some gas, initially at a temperature of 27.2 °C, is heated so that its temperature rises to 38.8 °C.
Calculate, in kelvin, to an appropriate number of decimal places,

(i) the initial temperature of the gas,

initial temperature = ... K [2]

(ii) the rise in temperature.

rise in temperature = ... K [1]

(b) The pressure p of an ideal gas is given by the expression

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

where ρ is the density of the gas.

(i) State the meaning of the symbol $\langle c^2 \rangle$.

....

....[1]

(ii) Use the expression to show that the mean kinetic energy $\langle E_K \rangle$ of the atoms of an ideal gas is given by the expression

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

Explain any symbols that you use.

....

....

....

....

.... [4]

For Examiner's Use

(c) Helium-4 may be assumed to behave as an ideal gas.
A cylinder has a constant volume of $7.8 \times 10^3 \, cm^3$ and contains helium-4 gas at a pressure of $2.1 \times 10^7 \, Pa$ and at a temperature of 290 K.

Calculate, for the helium gas,

(i) the amount of gas,

amount = ... mol [2]

(ii) the mean kinetic energy of the atoms,

mean kinetic energy = ... J [2]

(iii) the total internal energy.

internal energy = ... J [3]

2 (a) (i) State the basic assumption of the kinetic theory of gases that leads to the conclusion that the potential energy between the atoms of an ideal gas is zero.

....

.... [1]

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

....

....

.... [2]

(iii) Explain why an increase in internal energy of an ideal gas is directly related to a rise in temperature of the gas.

....

....

.... [2]

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

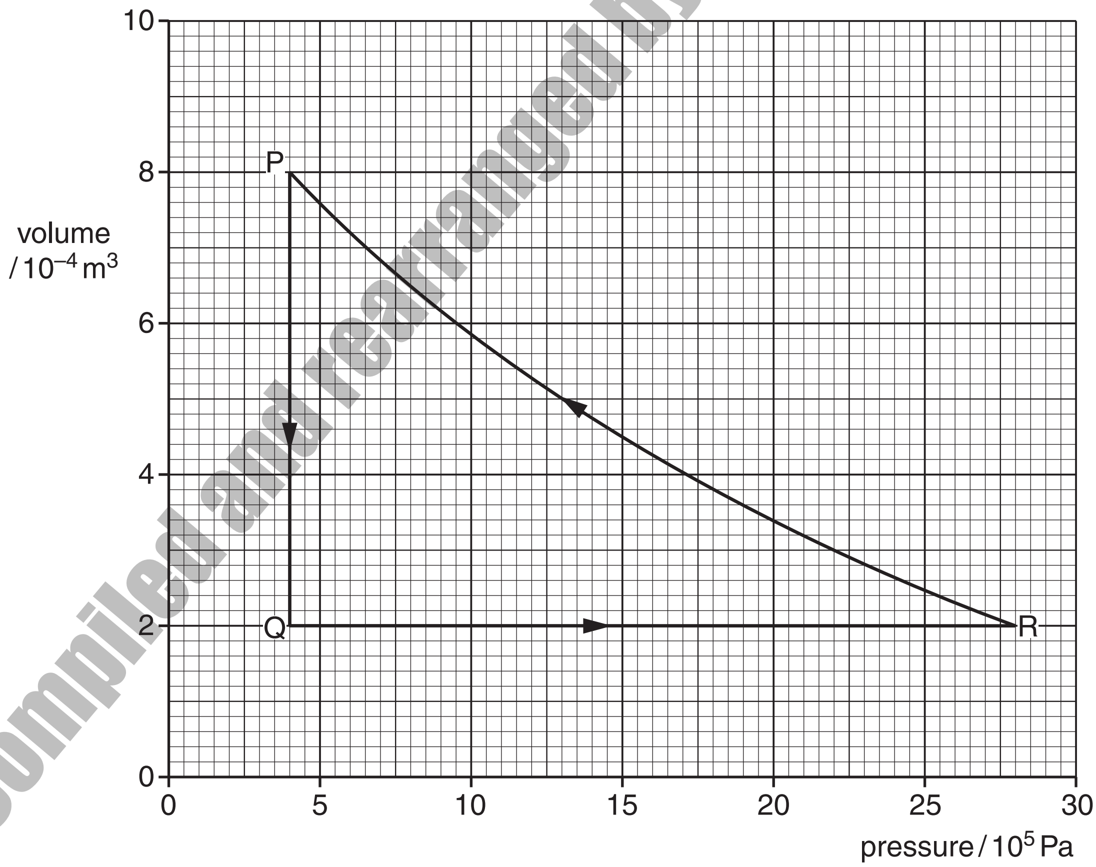

Fig. 2.1

For Examiner's Use

(i) State the change in internal energy of the gas during one complete cycle PQRP.

change = ... J [1]

(ii) Calculate the work done on the gas during the change from P to Q.

work done = ... J [2]

(iii) Some energy changes during the cycle PQRP are shown in Fig. 2.2.

change	work done on gas / J	heating supplied to gas / J	increase in internal energy / J
P → Q	....	–600	....
Q → R	0	+720	....
R → P	....	+480	....

Fig. 2.2

Complete Fig. 2.2 to show all of the energy changes. [3]

For Examiner's Use

2 **(a)** State the basic assumptions of the kinetic theory of gases.

....

....

....

....

....

.... [4]

(b) Use equations for the pressure of an ideal gas to deduce that the average translational kinetic energy $\langle E_K \rangle$ of a molecule of an ideal gas is given by the expression

$$\langle E_K \rangle = \frac{3}{2}\frac{R}{N_A}T$$

where R is the molar gas constant, N_A is the Avogadro constant and T is the thermodynamic temperature of the gas.

[3]

(c) A deuterium nucleus ^2_1H and a proton collide. A nuclear reaction occurs, represented by the equation

$$^2_1H + ^1_1p \longrightarrow ^3_2He + \gamma.$$

(i) State and explain whether the reaction represents nuclear fission or nuclear fusion.

....

....

.... [2]

(ii) For the reaction to occur, the minimum total kinetic energy of the deuterium nucleus and the proton is 2.4×10^{-14} J.
Assuming that a sample of a mixture of deuterium nuclei and protons behaves as an ideal gas, calculate the temperature of the sample for this reaction to occur.

For Examiner's Use

temperature = ... K [3]

(iii) Suggest why the assumption made in **(ii)** may not be valid.

....

....[1]

2 **(a)** State what is meant by the *Avogadro constant* N_A.

For Examiner's Use

....

....

.... [2]

(b) A balloon is filled with helium gas at a pressure of 1.1×10^5 Pa and a temperature of 25 °C.
The balloon has a volume of $6.5 \times 10^4 \, cm^3$.
Helium may be assumed to be an ideal gas.

Determine the number of gas atoms in the balloon.

number = ... [4]

For Examiner's Use

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

....

....

.... [2]

(b) Two containers A and B are joined by a tube of negligible volume, as illustrated in Fig. 2.1.

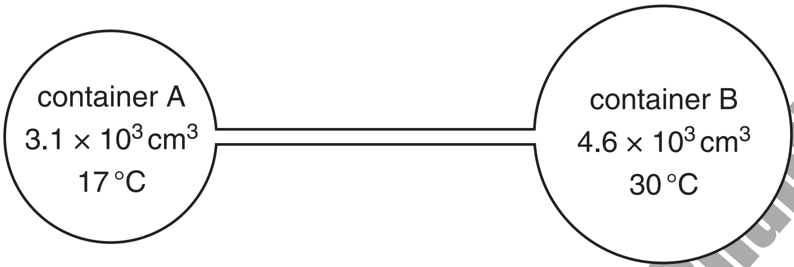

Fig. 2.1

The containers are filled with an ideal gas at a pressure of 2.3×10^5 Pa.
The gas in container A has volume $3.1 \times 10^3\,cm^3$ and is at a temperature of 17 °C.
The gas in container B has volume $4.6 \times 10^3\,cm^3$ and is at a temperature of 30 °C.

Calculate the total amount of gas, in mol, in the containers.

amount = ... mol [4]

For Examiner's Use

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

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

Explain the symbols in this expression.

+ ΔU ....

+ 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]