3 **(a)** With reference to molecular kinetic energy and molecular potential energy, explain what is meant by the internal energy of an ideal gas.

....

....

.... [2]

(b) A sample of an ideal gas is initially in state A, at a pressure of 2.0×10^5 Pa and with a volume of $0.016\,m^3$, as shown in Fig. 3.1.

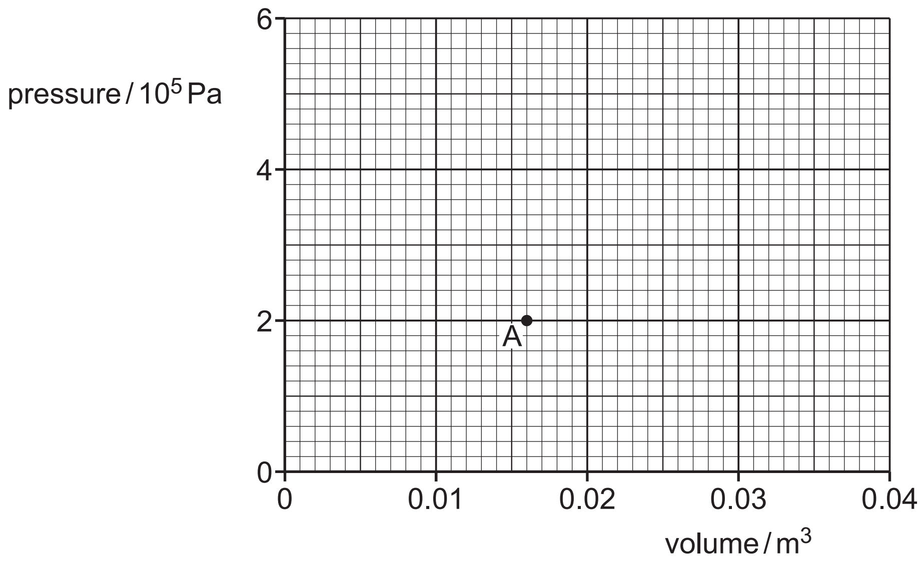

Fig. 3.1

In state A, the temperature of the gas is 400 K.

The gas undergoes two successive changes X and Y.

In change X, it is heated at constant volume to a pressure of 4.0×10^5 Pa. At the end of change X, the gas is in state B.

In change Y, it is then allowed to expand at constant temperature back to its original pressure. At the end of change Y, the gas is in state C.

(i) Determine the internal energy of the gas in state A.

internal energy = ... J [2]

(ii) Determine the temperature of the gas in state B.

temperature = ... K [1]

(iii) Determine the volume of the gas in state C.

volume = ... m^3 [1]

(iv) On Fig. 3.1, draw two lines, one to represent change X and one to represent change Y. Label your lines X and Y respectively. [3]

4 A cylinder contains a fixed mass of an ideal gas at pressure $2Y$ and volume $6X$.

The gas undergoes a sequence of changes from its initial state A, through states B, C and D, then finally back to its initial state A, as shown in Fig. 4.1.

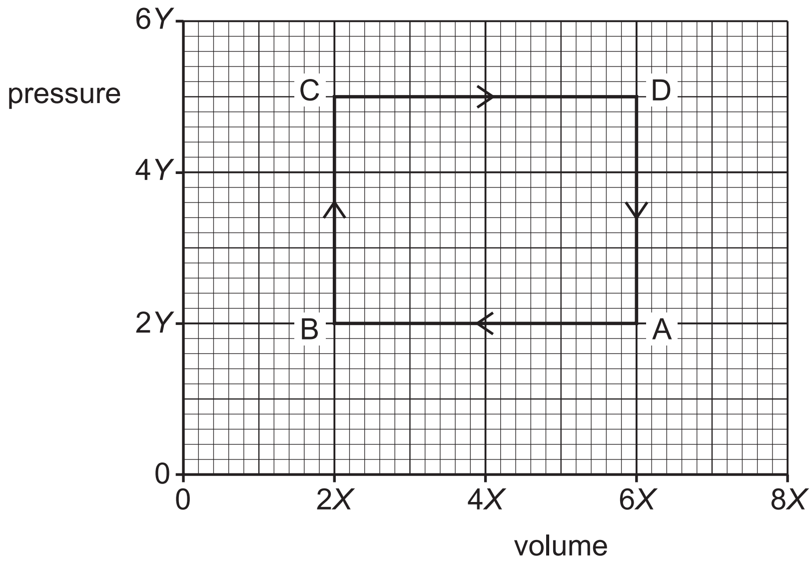

Fig. 4.1

Fig. 4.2 shows the variation with time of the internal energy of the gas.

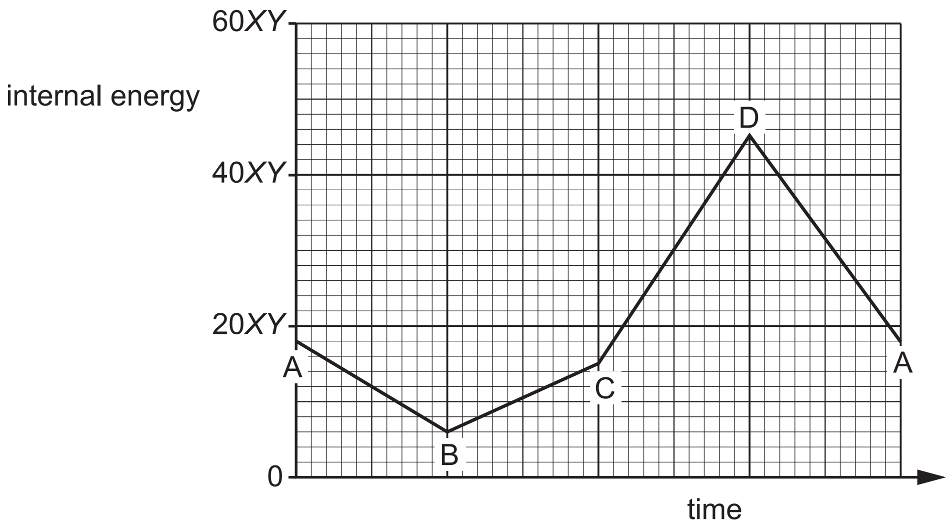

Fig. 4.2

(a) State the first law of thermodynamics.

....

....

.... [2]

(b) **(i)** Use Fig. 4.1 and Fig. 4.2 to determine the general expression for the internal energy U of the gas when it has pressure p and volume V.

U = ... [1]

(ii) An ideal gas at thermodynamic temperature T contains N molecules.

Use your answer in **(b)(i)** and the equation of state for an ideal gas to deduce an expression for U in terms of N and T. Identify any other symbols you use.

U = ... [2]

(c) Determine expressions, in terms of X and Y, for the work W done on the gas during:

(i) change AB

W = ... [1]

(ii) change CD.

W = ... [1]

(d) Use your answers in **(c)** and the first law of thermodynamics to determine an expression, in terms of X and Y, for the net thermal energy Q supplied to the gas during one full cycle ABCDA. Explain your reasoning.

Q = ... [3]

2 **(a)** State **two** ways in which the first law of thermodynamics describes that the internal energy of a system may be changed.

1 ....

....

2 ....

....
[2]

(b) **(i)** Use the first law of thermodynamics to explain why a bicycle pump gets hot when it is used to pump up a tyre quickly.

....

....

....

....

.... [3]

(ii) With reference to molecular energies, explain why the temperature of water remains at 100 °C when it vaporises in a kettle, even though it is being heated.

....

....

....

....

.... [3]

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

....

....

.... [2]

(b) An ideal gas at a pressure of 1.6×10^5 Pa has a density of $1.9\,\text{kg}\,\text{m}^{-3}$.

(i) Show that the root-mean-square (r.m.s.) speed of molecules of this gas is approximately $500\,\text{m}\,\text{s}^{-1}$.

[3]

(ii) One molecule of the gas has a mass of 4.7×10^{-26} kg.

Determine the thermodynamic temperature of the gas.

temperature = ... K [2]

(c) Calculate the internal energy U of 6.0 mol of the gas in **(b)**. Explain your reasoning.

U = ... J [3]

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

....

....

.... [2]

(b) A block of aluminium has a volume of $3.612 \times 10^{-3}\,m^3$ at a temperature of 0 °C.

Aluminium has a density of $2.700 \times 10^3\,kg\,m^{-3}$ at 0 °C.
It has a density of $2.620 \times 10^3\,kg\,m^{-3}$ at 500 °C.

The block is heated so that its temperature increases from 0 °C to 500 °C at an atmospheric pressure of $1.01 \times 10^5\,Pa$.
The increase in internal energy of the block is 4.38 MJ.

(i) Calculate the mass of the block.

mass = ... kg [2]

(ii) Show that the volume of the block at a temperature of 500 °C is $3.722 \times 10^{-3}\,m^3$.

[1]

(iii) Use the information in **(b)(ii)** to determine the magnitude of the work done on the block when its temperature is raised from 0 °C to 500 °C.

work done = ... J [2]

(iv) Explain whether the work done on the block is positive or negative.

....

....

.... [2]

(v) Use the first law of thermodynamics to determine, to three significant figures, a value for the specific heat capacity of aluminium. Explain your reasoning. Give a unit with your answer.

specific heat capacity = ... unit .... [3]

(c) Without further calculation, suggest with a reason how doubling the pressure in **(b)** is likely to affect the answer in **(b)(v)**.

....

....

.... [1]

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

....

....

.... [2]

(ii) Explain why the internal energy of an ideal gas is directly proportional to the thermodynamic temperature of the gas.

....

....

....

.... [2]

(b) A sample of an ideal gas at thermodynamic temperature T has internal energy U.

The gas is compressed so that its temperature increases to $3T$.
During this compression, work W is done on the gas.

The gas is then cooled at constant volume so that its temperature decreases to $2T$.

Complete Table 4.1 to show, in terms of some or all of W, T and U, the work done on the gas, the thermal energy supplied to the gas and the increase in internal energy of the gas for each of the two processes.

Table 4.1

	work done on gas	thermal energy supplied to gas	increase in internal energy of gas
compression	$+W$		
cooling			

[4]

3 **(a)** Two metal cuboids P and Q are in thermal contact with each other.

(i) P and Q are in thermal equilibrium.

State what is meant by the term thermal equilibrium.

....

....

.... [2]

(ii) Data for P and Q are given in Table 3.1.

Table 3.1

	P	Q
specific heat capacity / $J\,kg^{-1}\,K^{-1}$	390	910
mass / kg	0.54	0.37

P and Q are initially both at the same temperature.

P is supplied with 24 kJ of thermal energy. After some time, P and Q are once again both at the same temperature as each other.

P and Q are perfectly insulated from the surroundings.

Determine the change in temperature ΔT of Q.

ΔT = ... K [3]

(b) Nitrogen may be assumed to be an ideal gas. A fixed amount of nitrogen gas is contained at a constant pressure of 1.6×10^5 Pa.

The variation of the volume V of the gas with the temperature θ of the gas is shown in Fig. 3.1.

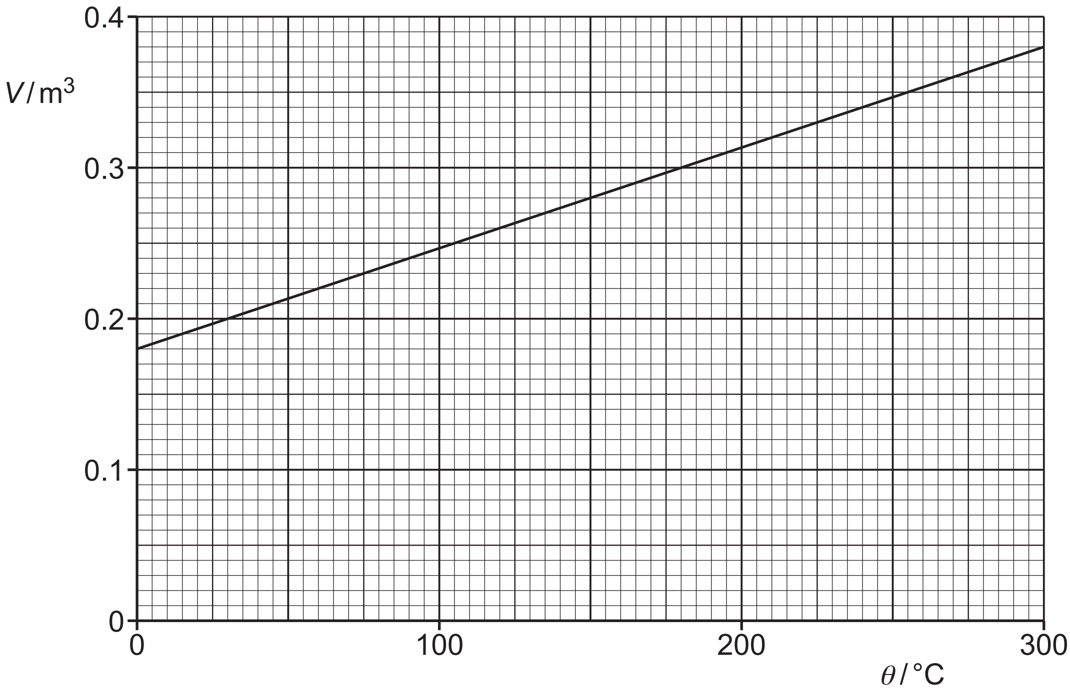

Fig. 3.1

(i) The temperature of the nitrogen gas is increased from 0 °C to 210 °C. Determine the work done on the gas.

work done = ... J [3]

(ii) Determine the number N of molecules of nitrogen gas.

N = ... [2]

(iii) The mass of a nitrogen molecule is 4.7×10^{-26} kg.

Calculate the root-mean-square (r.m.s.) speed of a nitrogen molecule at 210 °C.

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

BLANK PAGE

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

....

....

.... [2]

(b) With reference to molecular kinetic and potential energies, describe and explain how the internal energy of the system changes when:

(i) a gas is heated at constant volume so that its temperature increases

....

....

....

....

.... [3]

(ii) a wire is stretched within its elastic limit at constant temperature.

....

....

....

....

.... [3]

2 **(a)** By referring to both kinetic energy and potential energy, explain what is meant by the internal energy of an ideal gas.

....

....

....

.... [2]

(b) A fixed mass of an ideal gas at a temperature of 20 °C is sealed in a cylinder by a piston, as shown in Fig. 2.1.

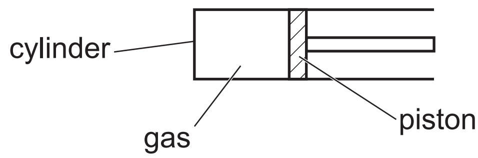

Fig. 2.1

The initial volume of the gas is $1.24 \times 10^{-4}\,m^3$.
Thermal energy is supplied to the gas and its volume increases by $5.20 \times 10^{-5}\,m^3$.

(i) The piston is freely moving so that the gas is always at atmospheric pressure.

Atmospheric pressure is $1.01 \times 10^5\,Pa$.

Calculate the work done by the gas.

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

(ii) Calculate the final thermodynamic temperature T of the gas.

T = ... K [2]

(iii) The mass of the gas is 16 g. For this expansion, there is a net transfer of 960 J of thermal energy to the gas.

Calculate the specific heat capacity c of the gas at this pressure.

c = ... $\mathrm{J\,kg^{-1}\,K^{-1}}$ [2]

(c) The gas in **(b)** is allowed to return to its starting temperature. The piston is now fixed in position.

Thermal energy is supplied to increase the temperature to the same final temperature as in **(b)**.

Use the first law of thermodynamics to suggest and explain how the specific heat capacity of the gas for this situation compares with the value in **(b)(iii)**.

....

....

....

.... [3]

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]

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

....

....

.... [2]

(b) An ideal gas of mass 0.35 kg is heated at a constant pressure of 2.0×10^5 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]

(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]

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.

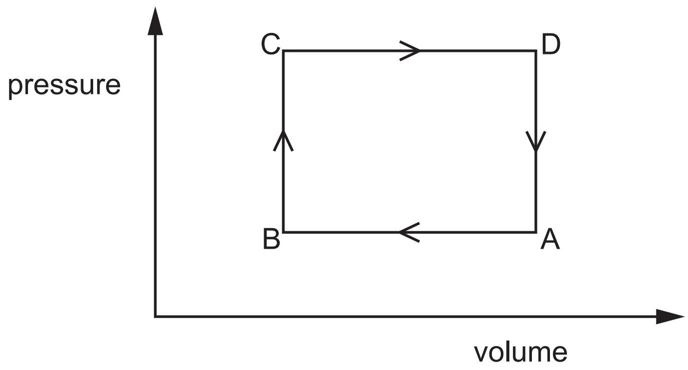

Fig. 3.1

(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]

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

....

....

....

....

.... [3]

3 **(a)** State the reason why two objects that are at the same temperature are described as being in thermal equilibrium.

....

.... [1]

(b) Fig. 3.1 shows the variations with temperature of the densities of mercury and of water between 0 °C and 100 °C.

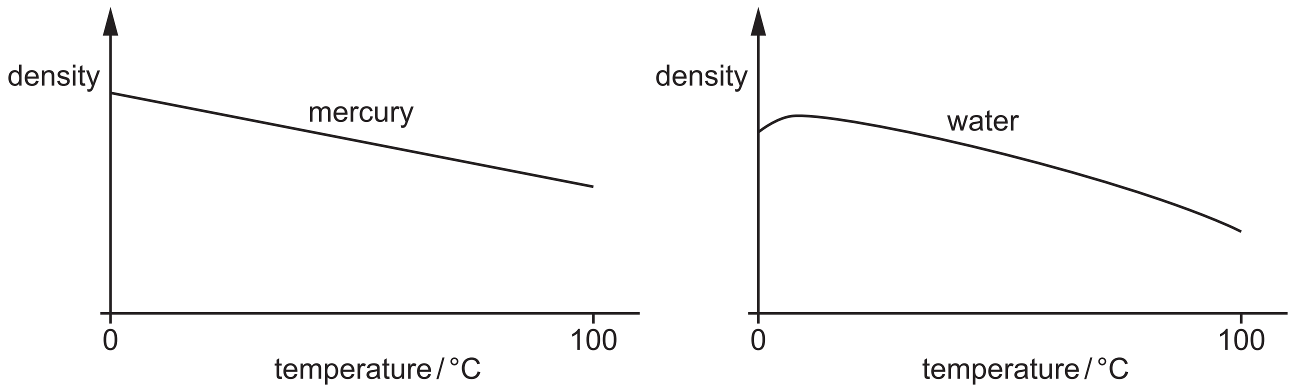

Fig. 3.1

Temperature may be measured using the variation with temperature of the density of a liquid.

Suggest why, for measuring temperature over this temperature range:

(i) mercury is a suitable liquid

....

.... [1]

(ii) water is not a suitable liquid.

....

....

.... [2]

(c) A beaker contains a liquid of mass 120 g. The liquid is supplied with thermal energy at a rate of 810 W. The beaker has a mass of 42 g and a specific heat capacity of 0.84 $J g^{-1} K^{-1}$. The beaker and the liquid are in thermal equilibrium with each other at all times and are insulated from the surroundings.

Fig. 3.2 shows the variation with time *t* of the temperature of the liquid.

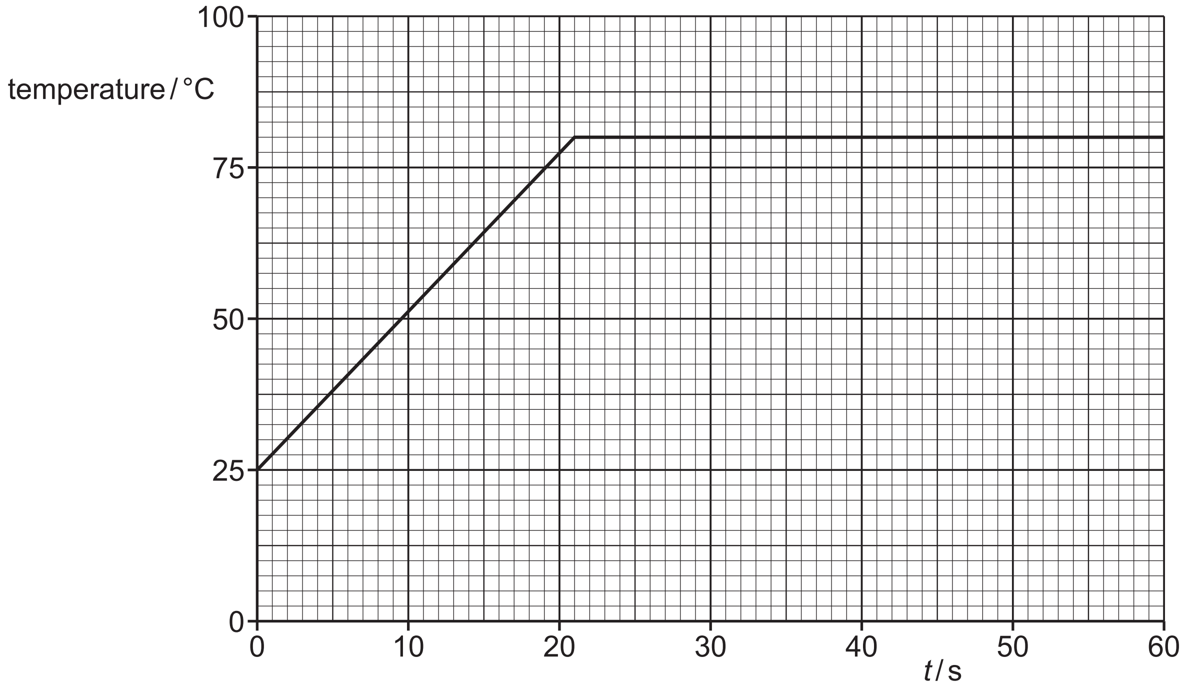

Fig. 3.2

(i) State the boiling temperature, in °C, of the liquid.

temperature = ... °C [1]

(ii) Determine the specific heat capacity, in $J\,g^{-1}\,K^{-1}$, of the liquid.

specific heat capacity = ... $J\,g^{-1}\,K^{-1}$ [4]

(d) The experiment in **(c)** is repeated using water instead of the liquid in **(c)**. The mass of liquid used, the power supplied, and the initial temperature are all unchanged.
The specific heat capacity of water is approximately twice that of the liquid in **(c)**.
The boiling temperature of water is 100 °C.

On Fig. 3.2, sketch the variation with time t of the temperature of the water between t = 0 and t = 60 s. Numerical calculations are not required. [2]

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

1 ....

....

2 ....

....
[2]

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

(i) Determine an expression for the temperature *T* of the gas in state X, in terms of *n*, *p* and *V*.
Identify any other symbols that you use.

[2]

(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.

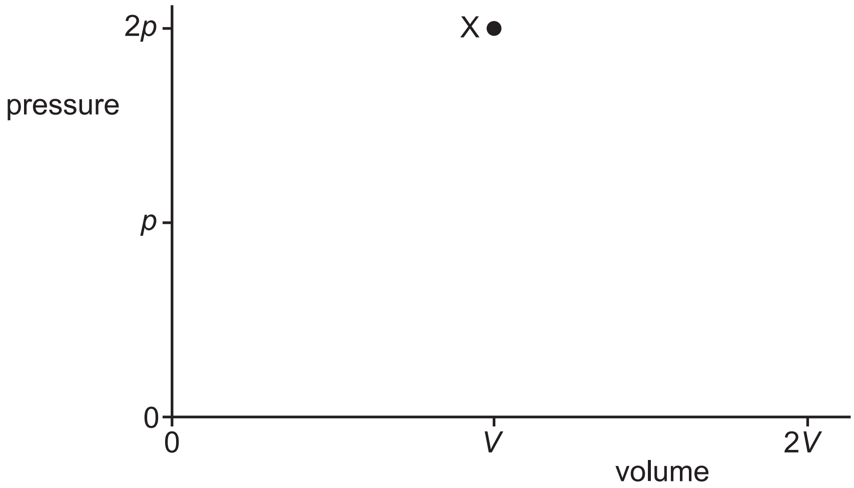

Fig. 4.1

[3]

(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]

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

....

....

.... [2]

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

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

initial state	final state
1.10×10^5 Pa	6.70×10^6 Pa
$540\,\text{cm}^3$	$30.0\,\text{cm}^3$
27 °C	742 °C

Fig. 2.1

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

(i) Show that the helium gas behaves as an ideal gas.

[2]

(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]

(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]

(c) The mass of nitrogen gas in another container is 24.0 g at a temperature of 27 °C. The gas is cooled to its boiling point of –196 °C. Assume all the gas condenses to a liquid.

For this change the specific heat capacity of nitrogen gas is 1.04 $kJ\,kg^{-1}\,K^{-1}$.

The specific latent heat of vaporisation of nitrogen is 199 $kJ\,kg^{-1}$.

Determine the thermal energy, in kJ, removed from the nitrogen gas.

energy = ... kJ [3]

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

....

....

.... [2]

(b) A fixed mass of water in a beaker is at atmospheric pressure.

(i) The initial temperature of the water is 0 °C.

The water is supplied with thermal energy E, so that its temperature increases to 8 °C. There is no net change in the volume of the water.

Use the first law of thermodynamics to complete Table 2.1 for this process.

Table 2.1

work done on water	thermal energy supplied to water	increase in internal energy of water
	+ E	

[2]

(ii) The water is now heated so that its temperature increases by a further 8 °C to a final temperature of 16 °C. This process causes the volume of the water to increase so that work W is done.
Assume that the change in internal energy is the same as in **(b)(i)**.

Use the first law of thermodynamics to complete Table 2.2 for this process.

Table 2.2

work done on water	thermal energy supplied to water	increase in internal energy of water

[2]

(c) Use the information in **(b)** to suggest, with a reason, how the average specific heat capacity of water between 8 °C and 16 °C compares with its average value between 0 °C and 8 °C.

....

.... [1]