16. Thermodynamics

16.2 The first law of thermodynamics

Paper 4

Question Paper

1 (b) A dish containing $7.2 \times 10^{-5}\,m^3$ of a substance rests on a laboratory bench. The substance is initially a liquid of density $710\,kg\,m^{-3}$. Atmospheric pressure is $1.0 \times 10^5\,Pa$.

The liquid is heated at its boiling point so that it completely vaporises. The increase in the internal energy of the substance during this process is 17.6 kJ. The final volume of the vapour is $0.017\,m^3$.

(i) Show that the magnitude of the work done on the substance when it vaporises is 1.7 kJ.

[2]

(ii) Use the information in **(b)(i)** to calculate the thermal energy Q, in kJ, supplied to the substance to cause it to vaporise.

Q = ... kJ [2]

2 **(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.

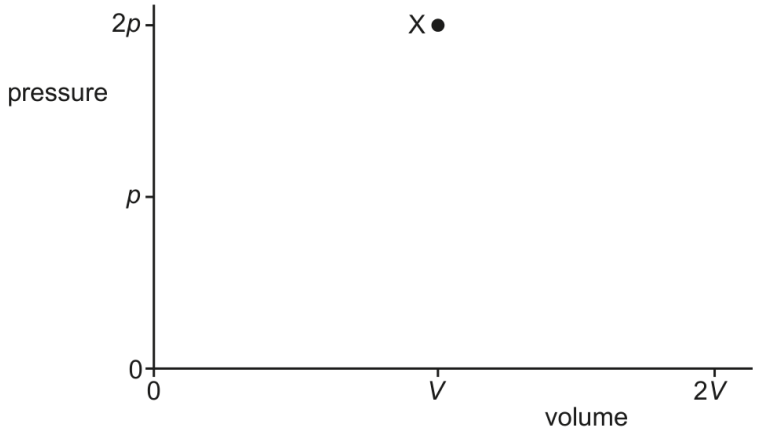


Fig. 4.1

[3]

(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]

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

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..... [2]

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

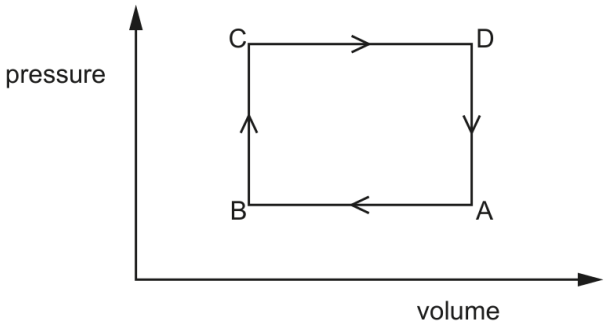


Fig. 3.1

(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.

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.....

..... [3]

4 **(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]

(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)**.

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.....

..... [3]

5 **(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

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..... [3]

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

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..... [3]

6 A fixed mass of an ideal gas is initially at a temperature of 17 °C.
The gas has a volume of 0.24 m^3 and a pressure of 1.2×10^5 Pa.

(b) The gas undergoes three successive changes, as shown in Fig. 3.1.

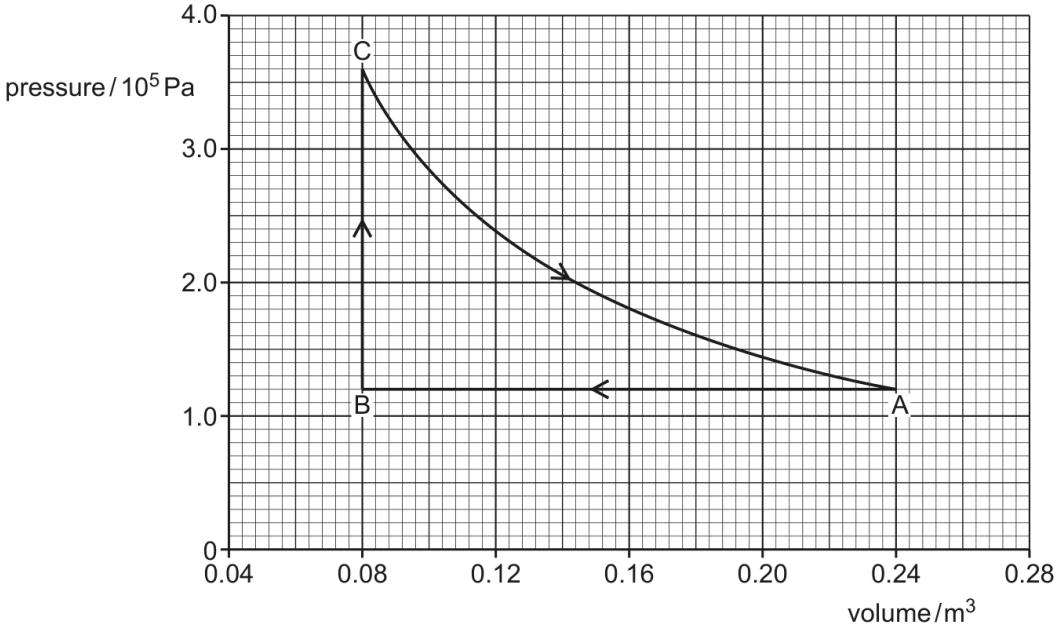


Fig. 3.1

The initial state is represented by point A. The gas is cooled at constant pressure to point B by the removal of 48.0 kJ of thermal energy.

The gas is then heated at constant volume to point C.

Finally, the gas expands at constant temperature back to its original pressure and volume at point A. During this expansion, the gas does 31.6 kJ of work.

(i) Show that the magnitude of the work done during the change AB is 19.2 kJ.

[2]

(ii) Complete Table 3.1 to show 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 changes AB, BC and CA.

Table 3.1

change	work done on gas / kJ	thermal energy supplied to gas / kJ	increase in internal energy of gas / kJ
AB		–48.0	
BC			
CA	–31.6		

[5]

7 **(b)** The specific latent heat of vaporisation of water at atmospheric pressure of 1.0×10^5 Pa is 2.3×10^6 J kg^{-1}. A mass of 0.37 kg of liquid water at 100 °C is provided with the thermal energy needed to vaporise all of the water at atmospheric pressure.

(iii) Assume that the initial volume of the liquid water is negligible compared with the volume of water vapour produced.

Determine the magnitude of the work done by the water in expanding against the atmosphere when it vaporises.

work done = ... J [2]

(iv) Use your answers in **(b)(i)** and **(b)(iii)** to determine the increase in internal energy of the water when it vaporises at 100 °C. Explain your reasoning.

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

(c) Use the first law of thermodynamics to suggest, with a reason, how the specific latent heat of vaporisation of water at a pressure greater than atmospheric pressure compares with its value at atmospheric pressure.

.....

.....

..... [2]

8 (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]

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

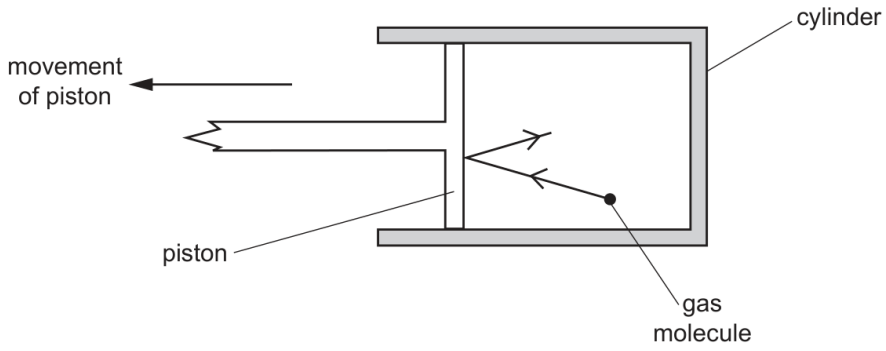


Fig. 2.1

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.

(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.

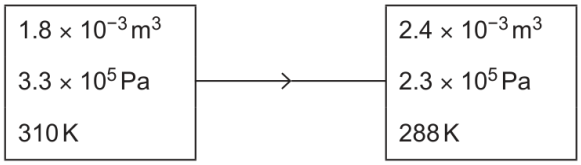


Fig. 2.2

(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.

.....

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..... [2]

10 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.

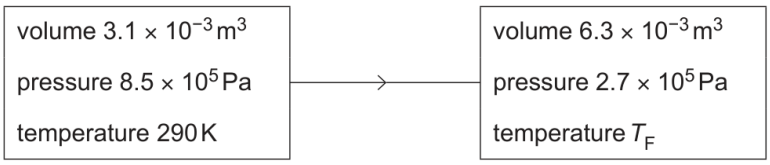


Fig. 2.1

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.

(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]

11 **(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.

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.....

..... [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)**.

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..... [2]

12 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

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..... [3]

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

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.....

.....

..... [3]

13 (a) The first law of thermodynamics may be expressed as

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

where ΔU is the increase in internal energy of the system.

State the meaning of:

$+q$ .....

.....

$+w$. .....

.....

[2]

(b) The variation with pressure p of the volume V of a fixed mass of an ideal gas is shown in Fig. 2.1.

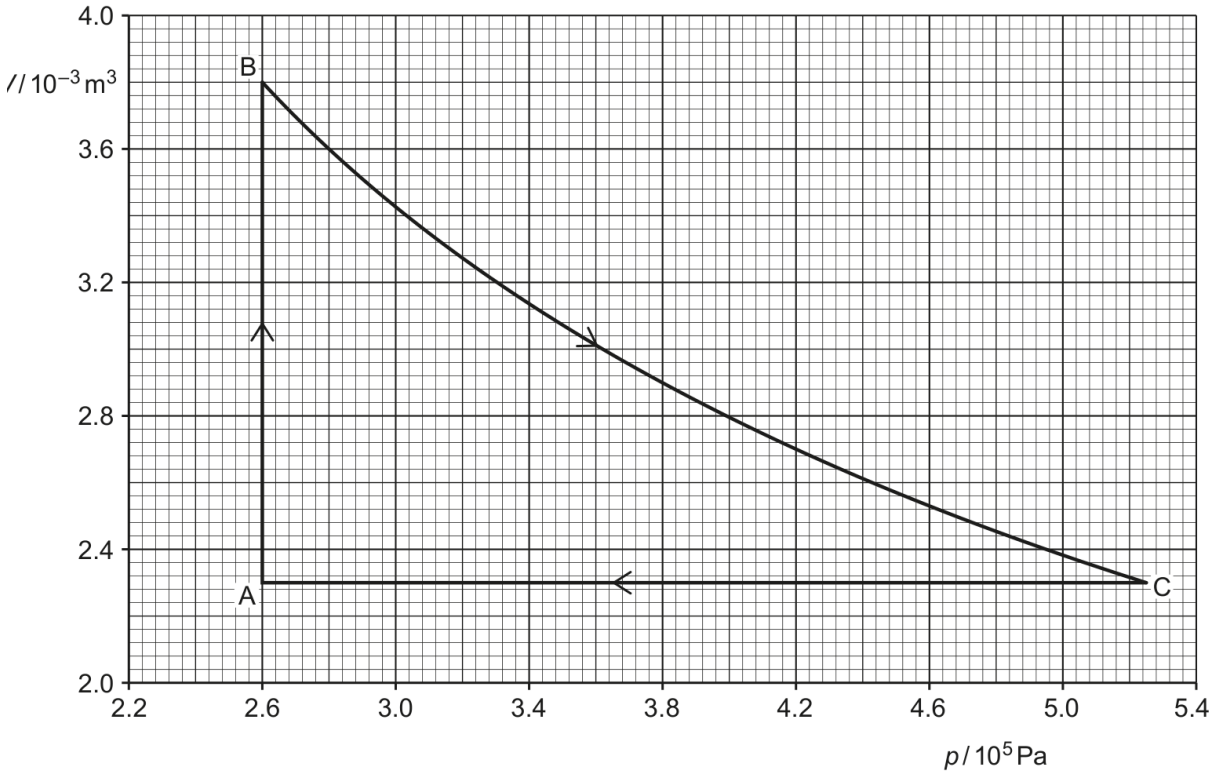


Fig. 2.1

The gas undergoes a cycle of changes A to B to C to A.

During the change A to B, the volume of the gas increases from $2.3 \times 10^{-3}\,m^3$ to $3.8 \times 10^{-3}\,m^3$.

(i) Show that the magnitude of the work done during the change A to B is 390 J.

[1]

(c) During the change A to B, 1370 J of thermal energy is transferred to the gas.

During the change B to C, no thermal energy enters or leaves the gas. The work done on the gas during this change is 550 J.

Use these data and the information in **(b)** to complete Table 2.1.

Table 2.1

change	q / J	w / J	ΔU / J
A to B	.....	.....	.....
B to C	.....	.....	.....
C to A	.....	.....	.....

[4]

14 (c) During the change in **(b)**, the thermal energy supplied to the gas is 980 J.

(i) Determine the work done on the gas during this change. Explain your working.

work done = ... J [3]

(ii) Determine the change ΔU in internal energy of the gas.

ΔU = ... J [1]

15 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.

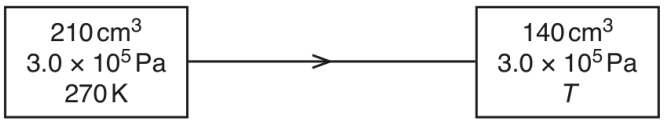


Fig. 2.1

The final temperature of the gas is T.

(a) Determine:

(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 ΔU, the change in internal energy of the gas.

ΔU = ... J [3]

16 (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.

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.....[1]

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

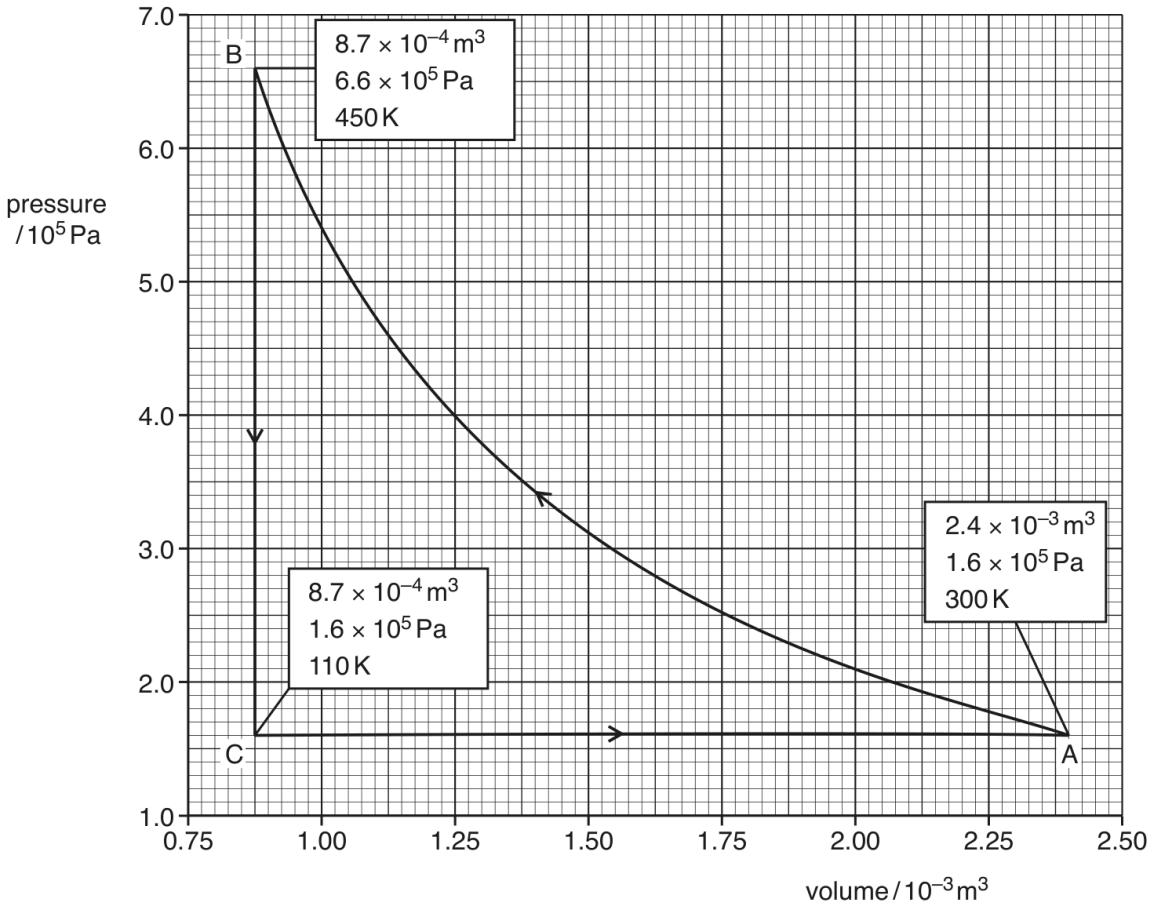


Fig. 2.1

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.

(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]

17 (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]

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

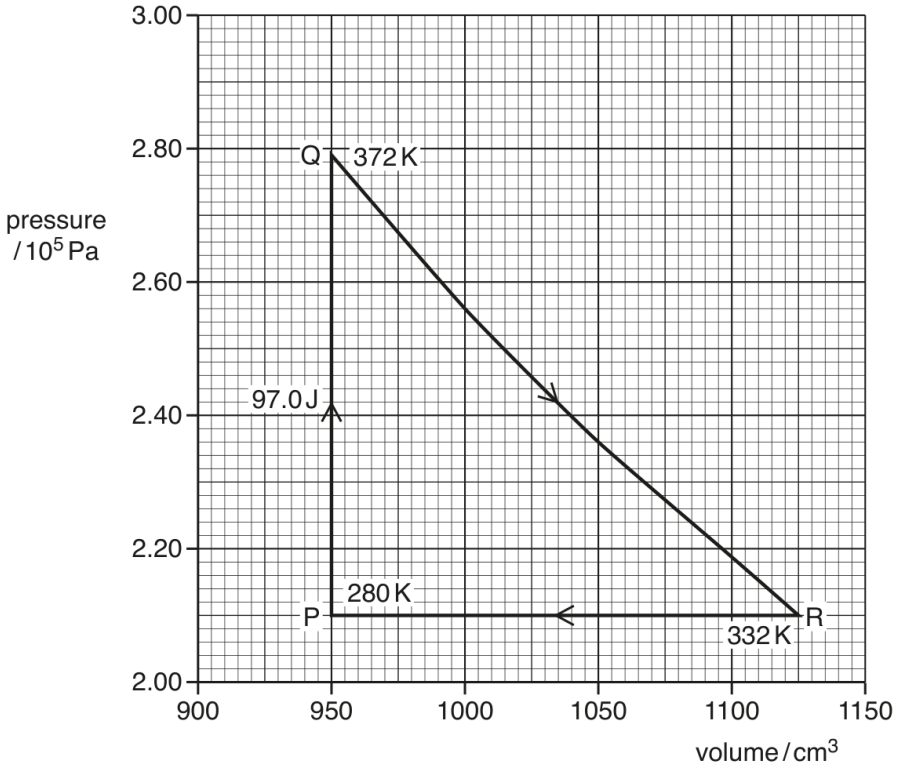


Fig. 2.1

At point P, the gas has volume 950 cm^3, pressure 2.10×10^5 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

(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]