16. Thermodynamics

16.1 Internal energy

Paper 4

Question Paper

1 **(b)** A sample of 0.26 m^3 of an ideal gas is at pressure 2.0×10^5 Pa and temperature 290 K.

Determine:

(iii) the internal energy of the gas. Explain your reasoning.

internal energy = ... J [2]

(c) The volume V of the gas in **(b)** is now varied, keeping its pressure constant.

On Fig. 3.1, sketch the variation with V of the internal energy U of the gas.



Fig. 3.1

[2]

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

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..... [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

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

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

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

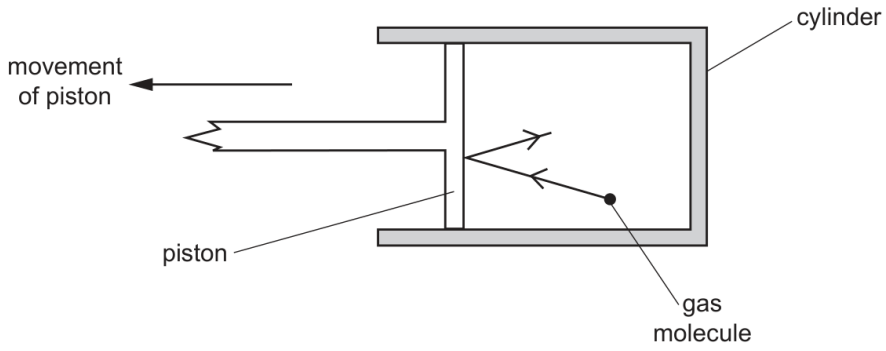


Fig. 2.1

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.

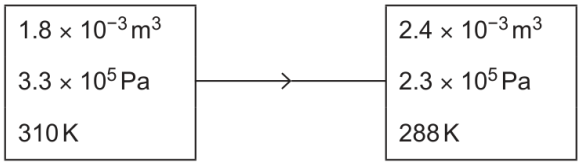


Fig. 2.2

(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 ΔU of the gas during the expansion.

ΔU = ... J [3]

5 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.

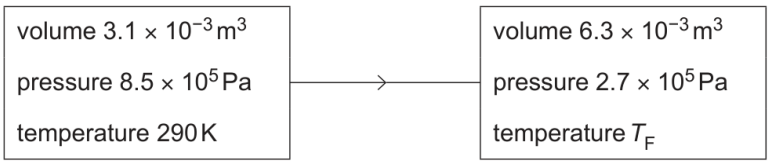


Fig. 2.1

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.

(b) (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 ΔU of the gas.

ΔU = ... J [3]

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

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

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

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(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.

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(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.

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

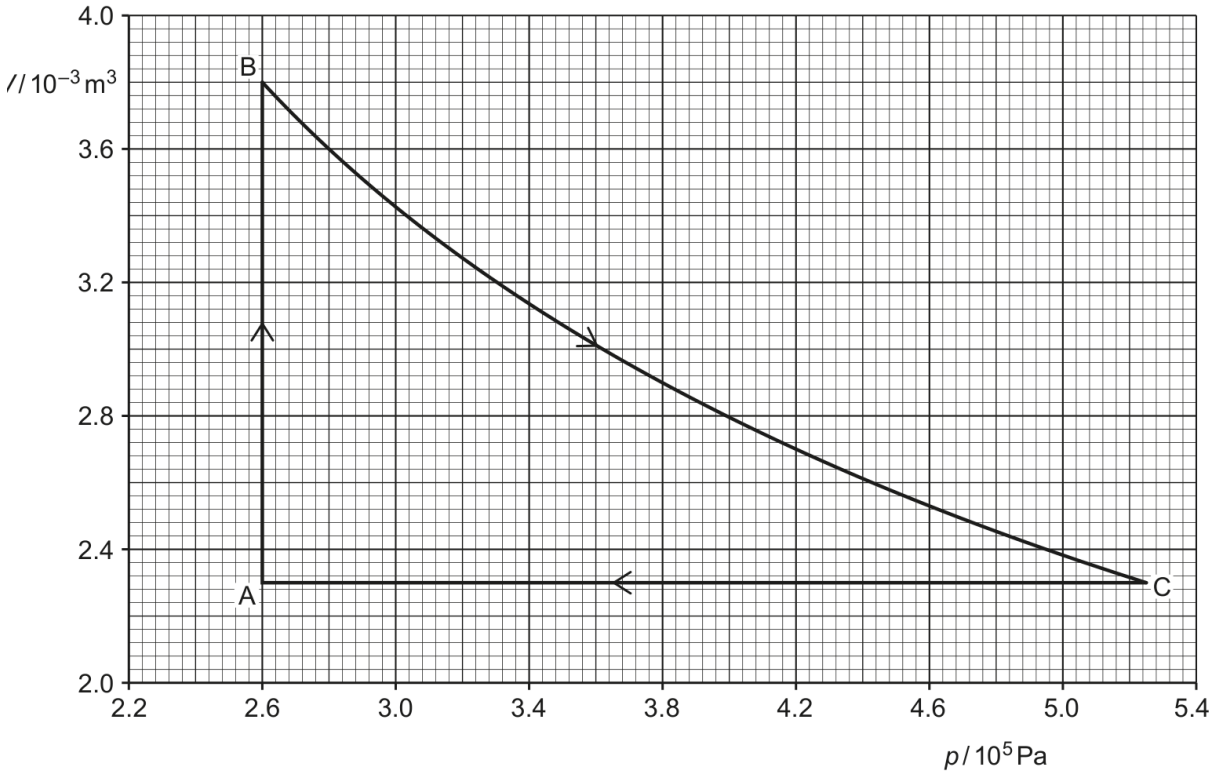


Fig. 2.1

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 $3.8 \times 10^{-3}\,m^3$.

(ii) State and explain the total change, if any, in the internal energy of the gas during one complete cycle.

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

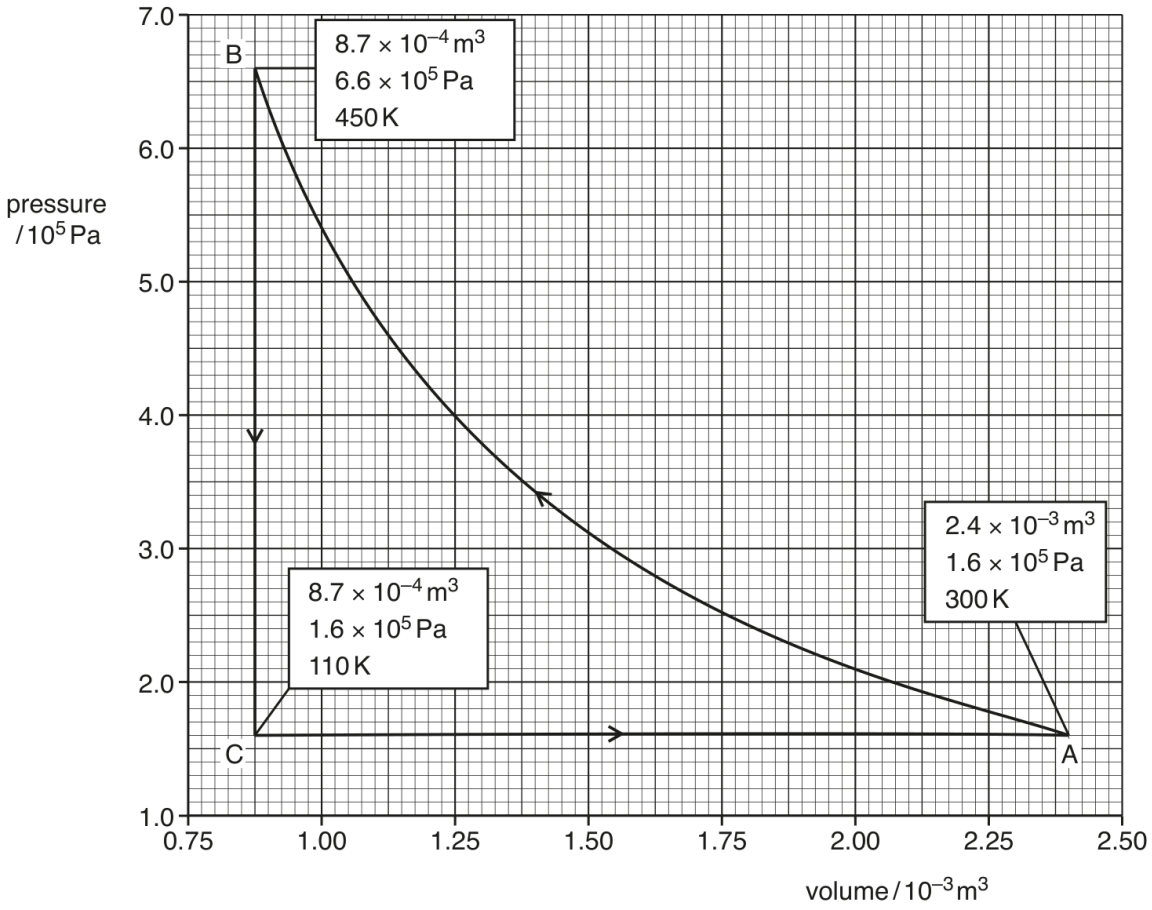


Fig. 2.1

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.

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

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

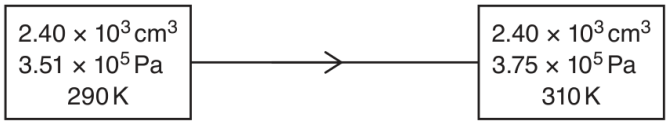


Fig. 2.1

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:

(ii) the thermal energy transfer during the change.

energy transfer = ... J [2]

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

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

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

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

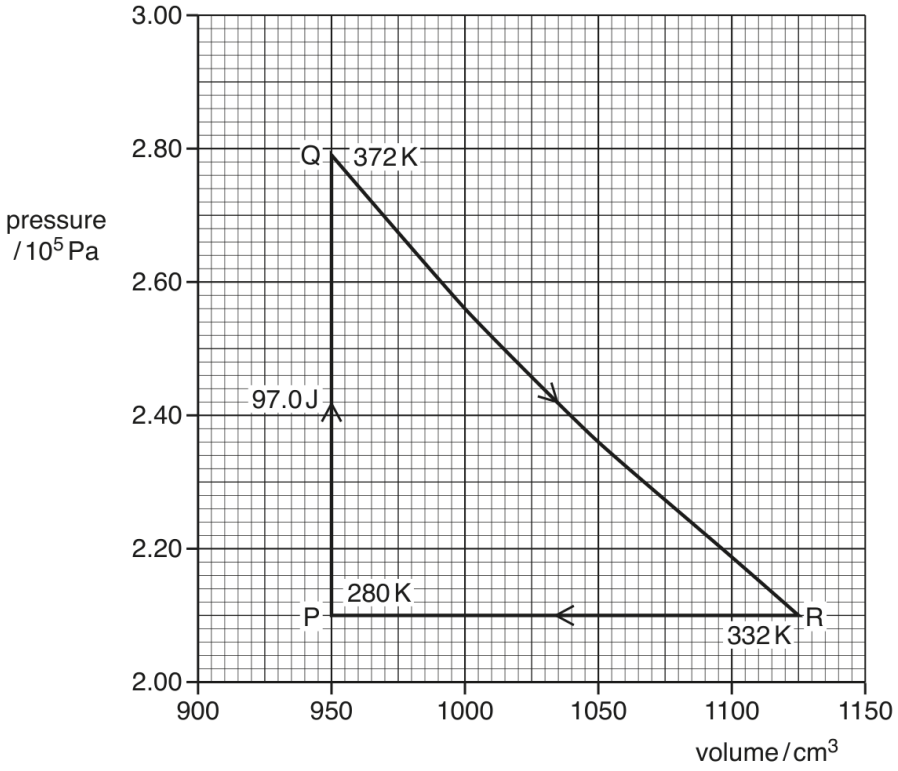


Fig. 2.1

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

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

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