HL Paper 2

This question is about an ideal gas.

a. Describe how the ideal gas constant *R* is defined. [2]

b. Calculate the temperature of 0.100 mol of an ideal gas kept in a cylinder of volume 1.40×10^{-3} m^3 at a pressure of 2.32×10^{5} Pa. [1]

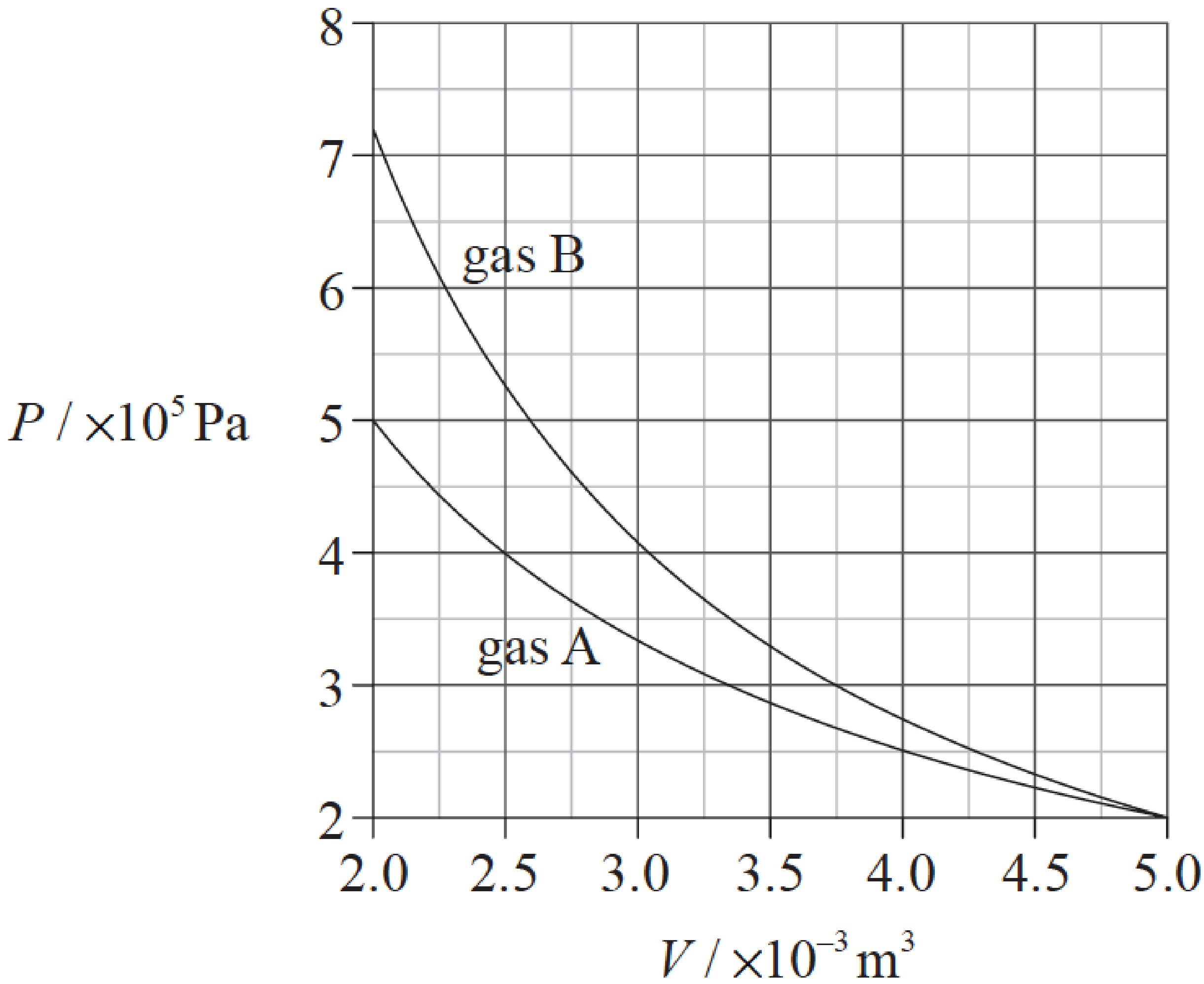
c. The gas in (b) is kept in the cylinder by a freely moving piston. The gas is now heated at constant pressure until the volume occupied by the gas is 3.60×10^{-3} m^3. The increase in internal energy of the gas is 760 J. Determine the thermal energy given to the gas. [2]

d. After heating, the gas is compressed rapidly to its original volume in (b). Outline why this compression approximates to an adiabatic change of state of the gas. [2]

Part 2 Properties of a gas

A fixed mass of an ideal gas is at an initial volume of 2.0×10^{-3} m^3. It undergoes an adiabatic expansion to a volume of 5.0×10^{-3} m^3. An identical ideal gas undergoes the same change of volume but this time isothermally.

The graph shows the variation with volume *V* of the pressure *P* of the two gases.



a. Using data from the graph above, identify which gas, A **or** B, undergoes the isothermal expansion. [2]

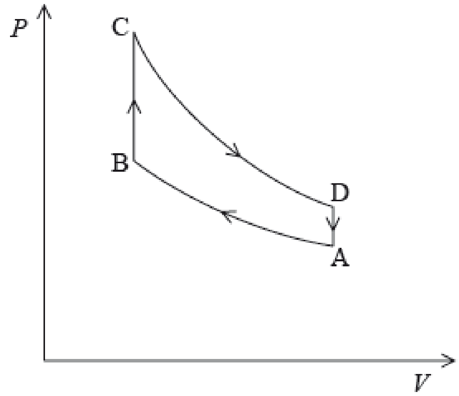
b. Using the graph opposite, estimate the difference in work done by each gas. [4]

c. Explain, with reference to the first law of thermodynamics, and without further calculation, the change in temperature of the gas undergoing the adiabatic change. [4]

This question is about the thermodynamics of a car engine and the dynamics of the car.

A car engine consists of four cylinders. In each of the cylinders, a fuel-air mixture explodes to supply power at the appropriate moment in the cycle.

The diagram models the variation of pressure *P* with volume *V* for one cycle of the gas, ABCDA, in one of the cylinders of the engine. The gas in the cylinder has a fixed mass and can be assumed to be ideal.



The car is travelling at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. At this speed, the energy provided by the fuel injected into one cylinder in each cycle is 9200 J. One litre of fuel provides 56 MJ of energy.

A car is travelling along a straight horizontal road at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. The power output required at the wheels is 0.13 MW.

A driver moves a car in a horizontal circular path of radius 200 m. Each of the four tyres will not grip the road if the frictional force between a tyre and the road becomes less than 1500 N.

a. At point A in the cycle, the fuel-air mixture is at 18 °C. During process AB, the gas is compressed to 0.046 of its original volume and the pressure increases by a factor of 40. Calculate the temperature of the gas at point B. [1]

b. State the nature of the change in the gas that takes place during process BC in the cycle. [1]

c. Process CD is an adiabatic change. Discuss, with reference to the first law of thermodynamics, the change in temperature of the gas in the cylinder during process CD. [3]

d. Explain how the diagram can be used to calculate the net work done during one cycle. [2]

e. (i) Calculate the volume of fuel injected into one cylinder during one cycle. [3]

(ii) Each of the four cylinders completes a cycle 18 times every second. Calculate the distance the car can travel on one litre of fuel at a speed of $56\ \mathrm{m\,s^{-1}}$.

f. A car accelerates uniformly along a straight horizontal road from an initial speed of $12\ \mathrm{m\,s^{-1}}$ to a final speed of $28\ \mathrm{m\,s^{-1}}$ in a distance of 250 m. The mass of the car is 1200 kg. Determine the rate at which the engine is supplying kinetic energy to the car as it accelerates. [4]

g. (i) Calculate the total resistive force acting on the car when it is travelling at a constant speed of $56\ \mathrm{m\,s^{-1}}$. [5]

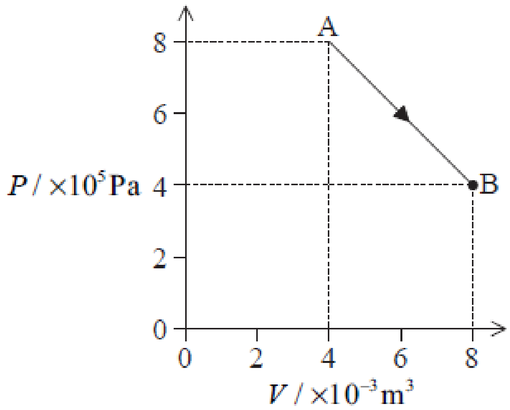
(ii) The mass of the car is 1200 kg. The resistive force *F* is related to the speed *v* by $F \propto v^2$. Using your answer to (g)(i), determine the maximum theoretical acceleration of the car at a speed of $28\ \mathrm{m\,s^{-1}}$.

h. (i) Calculate the maximum speed of the car at which it can continue to move in the circular path. Assume that the radius of the path is the same for each tyre. [6]

(ii) While the car is travelling around the circle, the people in the car have the sensation that they are being thrown outwards. Outline how Newton's first law of motion accounts for this sensation.

This question is about thermodynamics.

The *P–V* diagram shows the expansion of a fixed mass of an ideal gas, from state A to state B.



The temperature of the gas in state A is 400 K.

a. Calculate the temperature of the gas in state B. [1]

b. (i) Calculate the work done by the gas in expanding from state A to state B. [4]

(ii) Determine the amount of thermal energy transferred during the expansion from state A to state B.

c. The gas is isothermally compressed from state B back to state A. [3]

(i) Using the *P–V* diagram axes opposite, draw the variation of pressure with volume for this isothermal compression.

(ii) State and explain whether the magnitude of the thermal energy transferred in this case would be less than, equal to **or** greater than the thermal energy transferred in (b)(ii).

This question is about nuclear fission.

Some nuclear reactors have a heat exchanger that uses a gas that is kept at constant volume. The first law of thermodynamics can be represented as

$Q = \Delta U + W$.

(i) State the meanings of Q and W.

Q:

W:

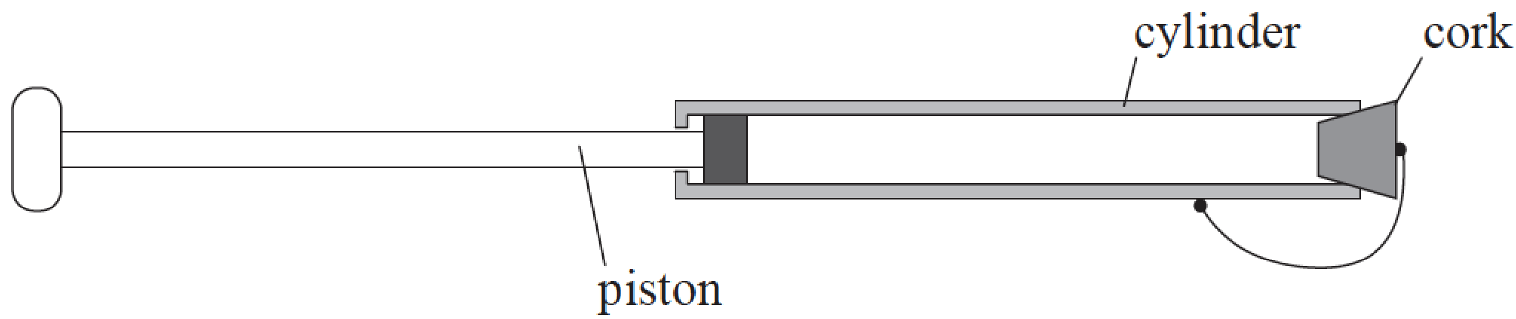
(ii) Describe how the first law of thermodynamics applies in the operation of the heat exchanger.

(iii) Discuss the entropy changes that take place in the gas and in the surroundings.

This question is in **two** parts. **Part 1** is about processes in a gas. **Part 2** is about rocket motion.

Part 1 Processes in a gas

In a toy, the air in a cylinder is compressed quickly by a piston. The diagram shows the toy before the air is compressed.



The air in the cylinder can be regarded as an ideal gas. Before compression, the air in the cylinder is at a pressure of 1.1×10^{5}Pa and a temperature of 290K. The volume of the air in the cylinder is 6.0×10^{-4}m^{3}.

a. Calculate the number of moles of air in the cylinder. [2]

b. The cork leaves the toy after the air is compressed to a pressure of 1.9×10^{5}Pa and a volume of 4.0×10^{-4} m^{3}. [9]

(i) Deduce that the compression of the gas is not isothermal.

(ii) Outline why the compression might be adiabatic.

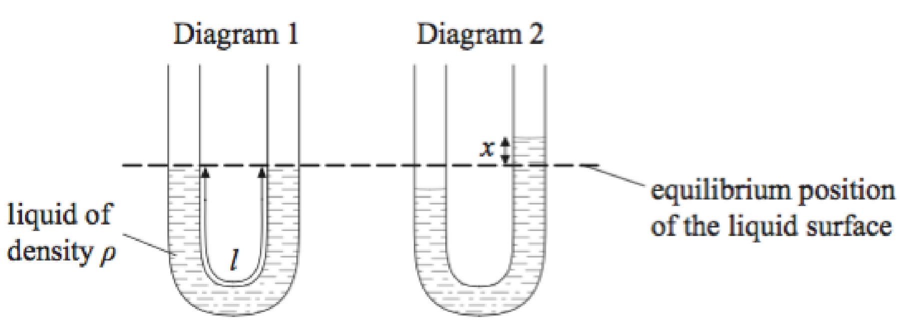
(iii) The work needed to compress the air in (a) is 15J. Determine, with reference to the first law of thermodynamics, the change in the internal energy of the air in the cylinder.

(iv) Calculate the change in average kinetic energy of an air molecule as a result of the compression.

c. The piston is now pushed in slowly so that the compression is isothermal. Discuss the entropy changes that take place in the air of the toy and in its cylinder as the air is compressed. [4]

This question is about simple harmonic motion (SHM), wave motion and polarization.

b. A liquid is contained in a U-tube. [7]



The pressure on the liquid in one side of the tube is increased so that the liquid is displaced as shown in diagram 2. When the pressure is suddenly released the liquid oscillates. The damping of the oscillations is small.

(i) Describe what is meant by damping.

(ii) The displacement of the liquid surface from its equilibrium position is x. The acceleration a of the liquid in the tube is given by the expression

$a=-\frac{2g}{l}x$

where g is the acceleration of free fall and l is the total length of the liquid column. Explain, with reference to the motion of the liquid, the significance of the minus sign.

(iii) The total length of the liquid column in the tube is 0.32m. Determine the period of oscillation.

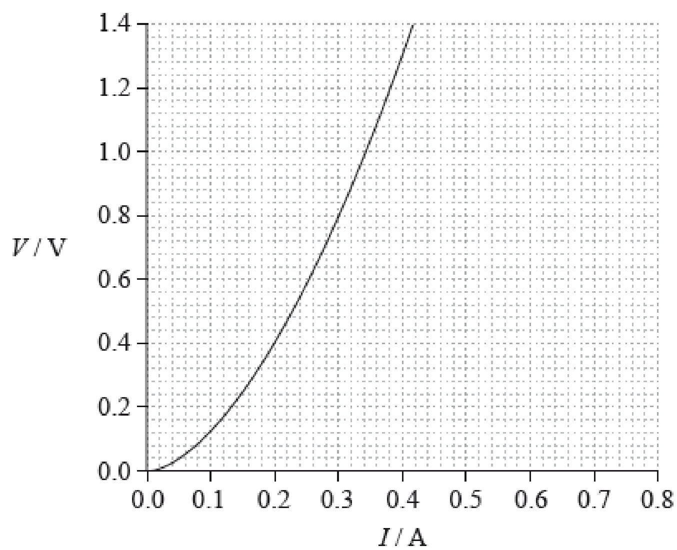
d. The string in (c) is fixed at both ends and is made to vibrate in a vertical plane in its first harmonic. [6]

(i) Describe how the standing wave in the string gives rise to the first harmonic.
(ii) Outline how a travelling wave in a string can be used to describe the nature of polarized light.

This question is in **two** parts. **Part 1** is about internal resistance of a cell. **Part 2** is about expansion of a gas.

Part 1 Internal resistance of a cell

The graph shows the voltage–current (V–I) characteristics of a non-ohmic conductor.



The variable resistor in the circuit in (c) is replaced by this non-ohmic conductor.

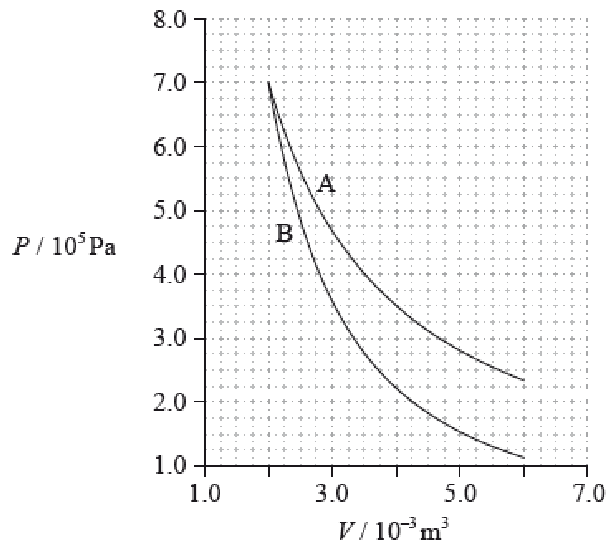
Part 2 Expansion of a gas

b. Outline, with reference to charge carriers, what is meant by the internal resistance of a cell. [3]

d.i. On the graph, sketch the variation of V with I for the cell. [2]

d.ii. Using the graph, determine the current in the circuit. [3]

e. The graph shows how the pressure P of a fixed mass of gas varies with volume V. The lines show the state of the gas sample during adiabatic expansion and during isothermal expansion. [2]



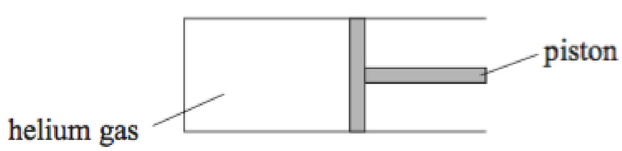
State and explain whether line A **or** line B represents an adiabatic expansion.

f. Determine the work done during the change represented by line A. [4]

g. Outline, with reference to the first law of thermodynamics, the direction of change in temperature during the adiabatic expansion. [4]

This question is about changes of state of a gas.

a. A cylinder fitted with a piston contains 0.23 mol of helium gas. [3]



The following data are available for the helium with the piston in the position shown.

Volume = $5.2\times10^{-3}m^3$

Pressure = 1.0×10^5 Pa

Temperature = 290K

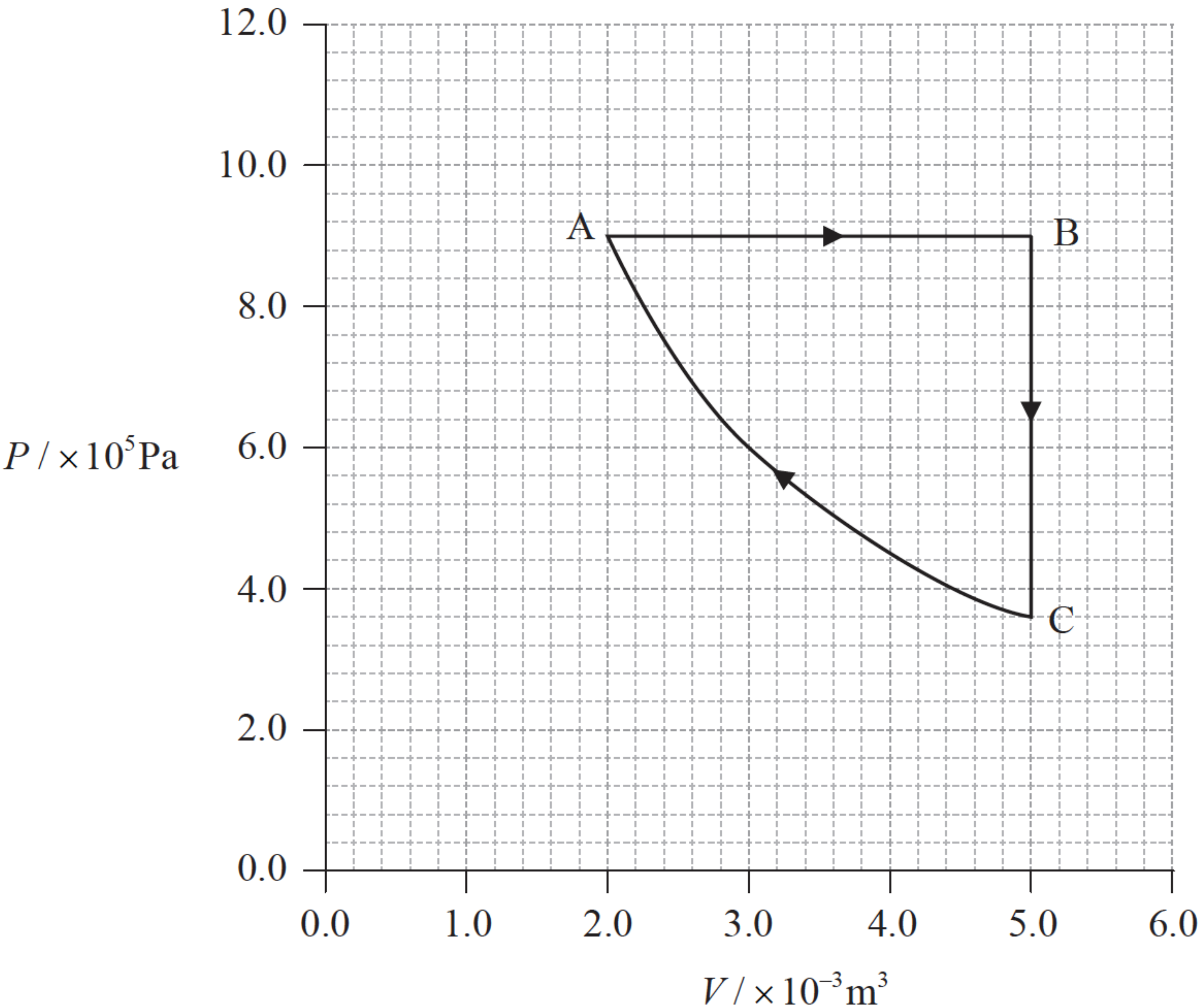
(i) Use the data to calculate a value for the universal gas constant.
(ii) State the assumption made in the calculation in (a)(i).

b. The gas is now compressed isothermally by the piston so that the volume of the gas is reduced. Explain why the compression must be carried out slowly. [2]

c. After the compression, the gas is now allowed to expand adiabatically to its original volume. Use the first law of thermodynamics to explain whether the final temperature will be less than, equal to or greater than 290K. [4]

Part 2 Thermodynamics

A fixed mass of an ideal gas undergoes the three thermodynamic processes, AB, BC and CA, represented in the *P–V* graph below.



a. State which of the processes is isothermal, isochoric (isovolumetric) or isobaric. [3]

Process AB:

Process BC:

Process CA:

b. The temperature of the gas at A is 300K. Calculate the temperature of the gas at B. [2]

c. The increase in internal energy of the gas during process AB is 4100J. Determine the heat transferred to the gas from the surroundings during the process AB. [2]

d. The gas is compressed at constant temperature. Explain what changes, if any, occur to the entropy of [3]

(i) the gas.

(ii) the surroundings.

(iii) the universe.

Part 2 Properties of a gas

a. With respect to a gas, explain the meaning of the terms thermal energy and internal energy. [2]

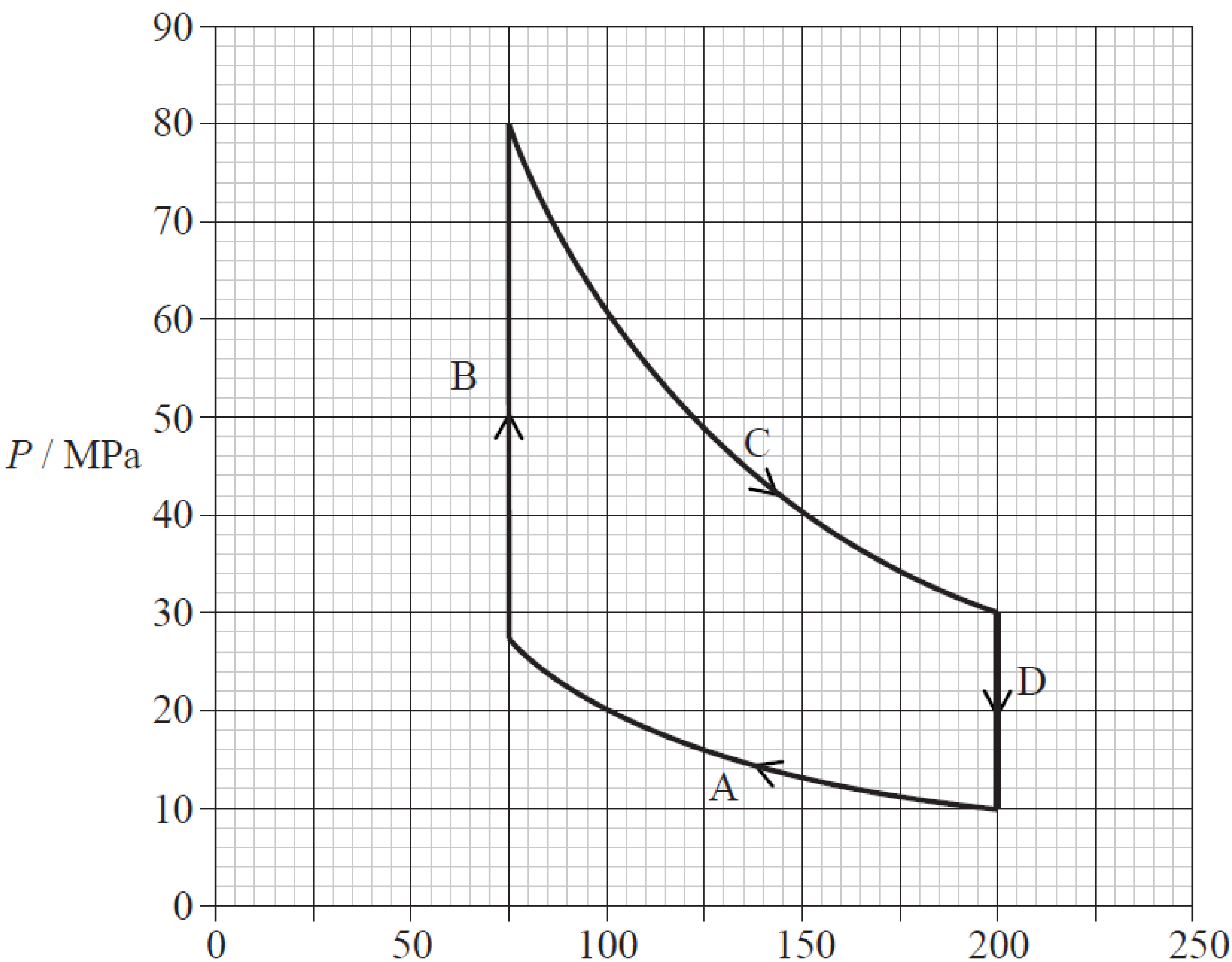
Thermal energy: . . . .

. . . .

Internal energy: . . . .

. . . .

b. The graph shows how the pressure *P* of a sample of a fixed mass of an ideal gas varies with volume *V*. The gas is taken through a cycle **ABCD.** [10]



V / 10^{-6} m^3

(i) Estimate the net work done during the cycle.

(ii) Explain whether the net work is done on the gas or by the gas.

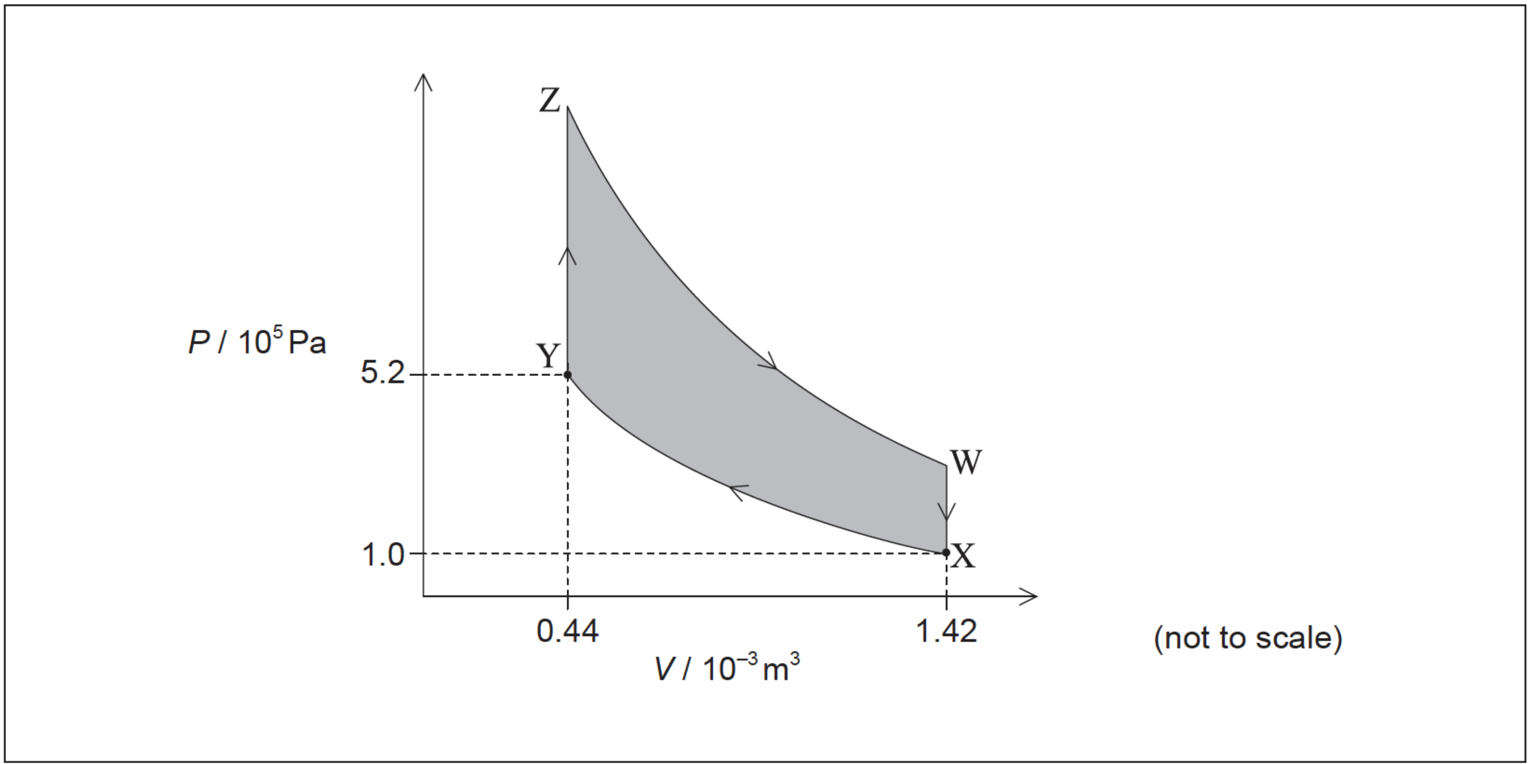
(iii) Deduce, using the data from the graph, that the change **C** is isothermal.

(iv) Isothermal change **A** occurs at a temperature of 450 K. Calculate the temperature at which isothermal change **C** occurs.

(v) Describe the changes **B** and **D**.

Part 2 Gas in an engine

A fixed mass of an ideal gas is used as the working substance in an engine. The graph shows the variation with volume *V* of the pressure *P* of the fluid.



e. For the cycle identify, with the letter I, an isochoric (isovolumetric) change. [1]

f. The temperature at point X is 310 K. Calculate the temperature at point Y. [2]

g. The shaded area WXYZ is 610 J. The total thermal energy transferred out of the gas in one cycle is 1.3 kJ. [5]

(i) State what is represented by the shaded area WXYZ.

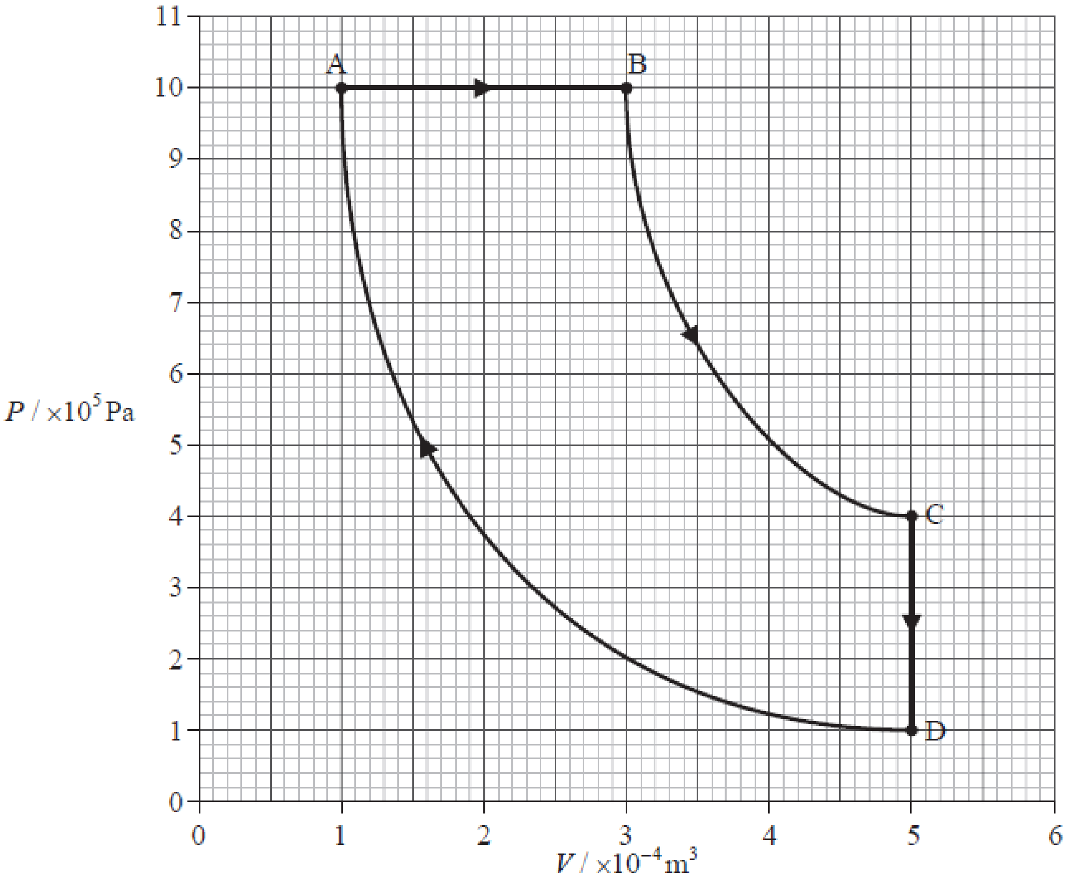
(ii) Determine the efficiency of cycle WXYZ.

(iii) Explain why the total thermal energy transferred out of the gas is degraded.

h. The work done on the gas during the adiabatic compression XY is 210 J. Determine the change in internal energy during the change from X to Y. [2]

Part 2 Thermodynamic cycles

a. A gas undergoes a thermodynamic cycle. The *P*–*V* diagram for the cycle is shown below. [3]



In the changes of state B to C and D to A, the gas behaves as an ideal gas and the changes in state are adiabatic.

(i) State the circumstances in which the behaviour of a gas approximates to ideal gas behaviour.

(ii) State what is meant by an adiabatic change of state.

b. With reference to the first law of thermodynamics, explain for the change of state A to B, why energy is transferred from the surroundings to the gas. [4]

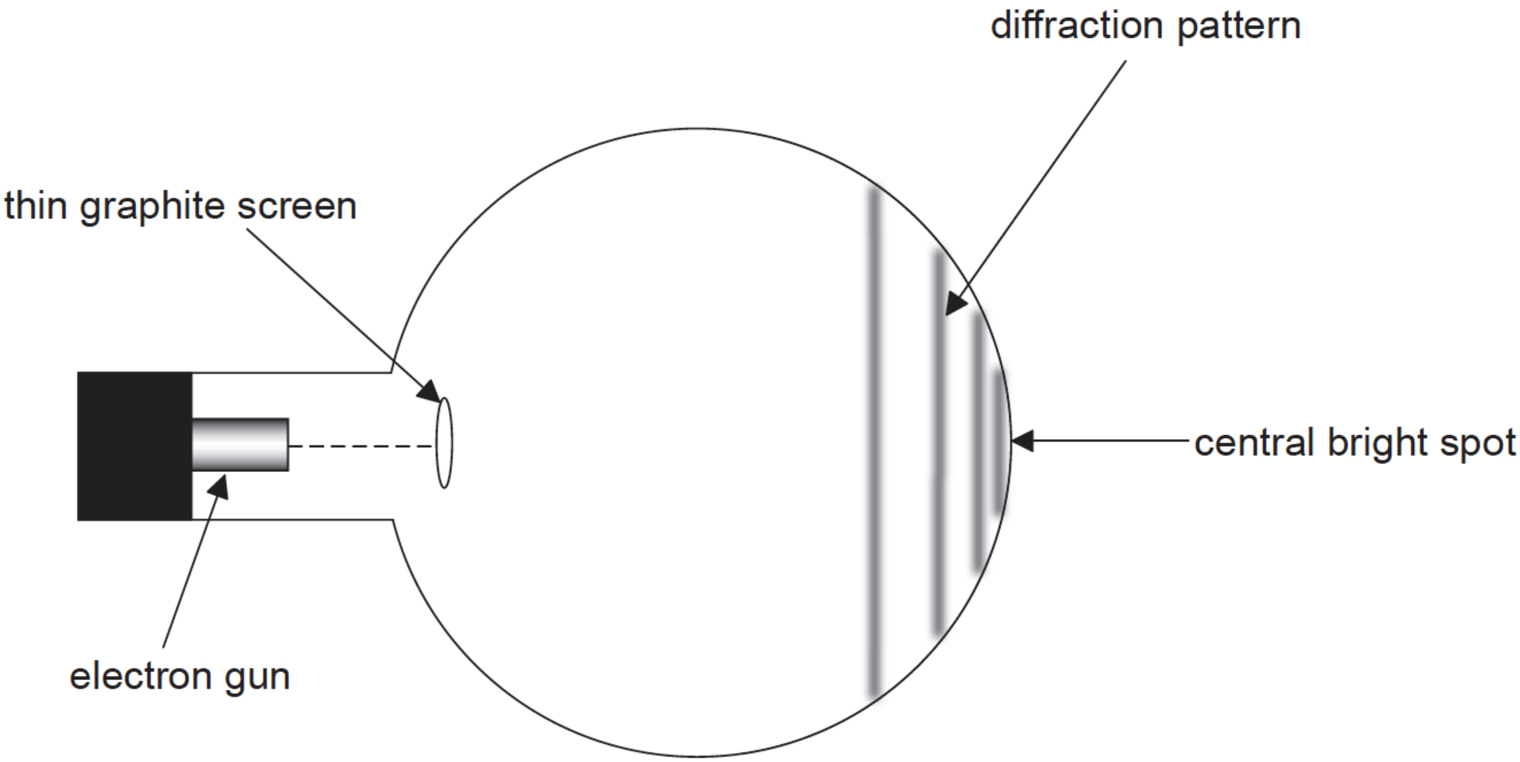
c. Estimate the total work done in the cycle. [3]

This question is in two parts. **Part 1** is about thermal properties of matter. **Part 2** is about quantum physics.

Part 1 Thermal properties of matter

Part 2 Quantum physics

The diagram shows the end of an electron diffraction tube.



A pattern forms when diffracted electrons are incident on a fluorescent layer at the end of the tube.

b. Three ice cubes at a temperature of 0ºC are dropped into a container of water at a temperature of 22ºC. The mass of each ice cube is 25 g and the mass of the water is 330 g. The ice melts, so that the temperature of the water decreases. The thermal capacity of the container is negligible. [8]

(i) The following data are available.

Specific latent heat of fusion of ice = 3.3×10^{5} J kg^{-1}
Specific heat capacity of water = 4.2×10^{3} J kg^{-1} K^{-1}

Calculate the final temperature of the water when all of the ice has melted. Assume that no thermal energy is exchanged between the water and the surroundings.

(ii) Explain how the first law of thermodynamics applies to the water when the ice cubes are dropped into it.

c. Explain how the pattern demonstrates that electrons have wave properties. [3]

d. Electrons are accelerated to a speed of 3.6×10^{7} ms^{-1} by the electric field. [5]

(i) Calculate the de Broglie wavelength of the electrons.

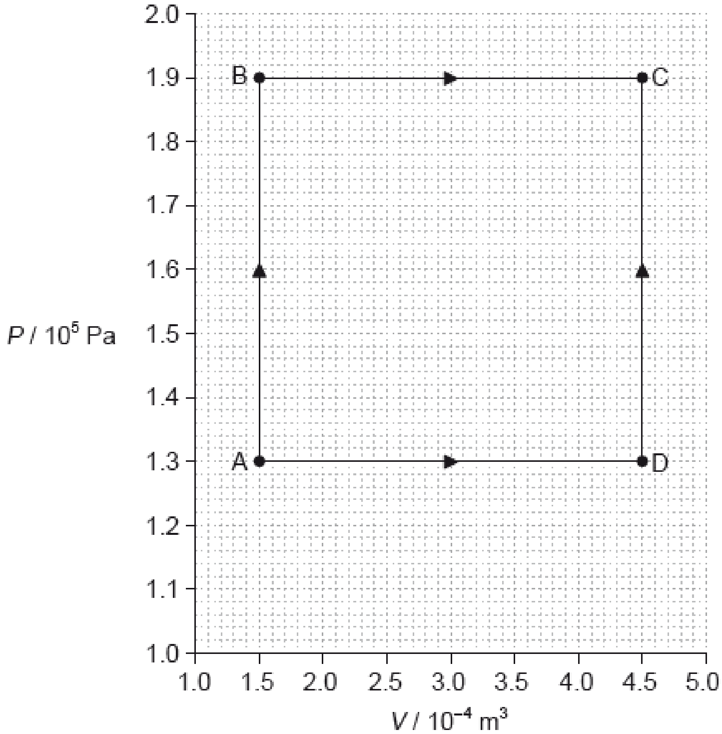
(ii) The cathode and anode are 22 mm apart and the field is uniform.
The potential difference between the cathode and the anode is 3.7 kV.
Show that the acceleration of the electrons is approximately 3×10^{16}ms^{-2}.

e. State what can be deduced about an electron from the amplitude of its associated wavefunction. [2]

f. An electron reaching the central bright spot on the fluorescent screen has a small uncertainty in its position. Outline what the Heisenberg uncertainty principle is able to predict about another property of this electron. [2]

This question is about an ideal gas.

The graph shows how the pressure P of a sample of fixed mass of an ideal gas varies with volume V.



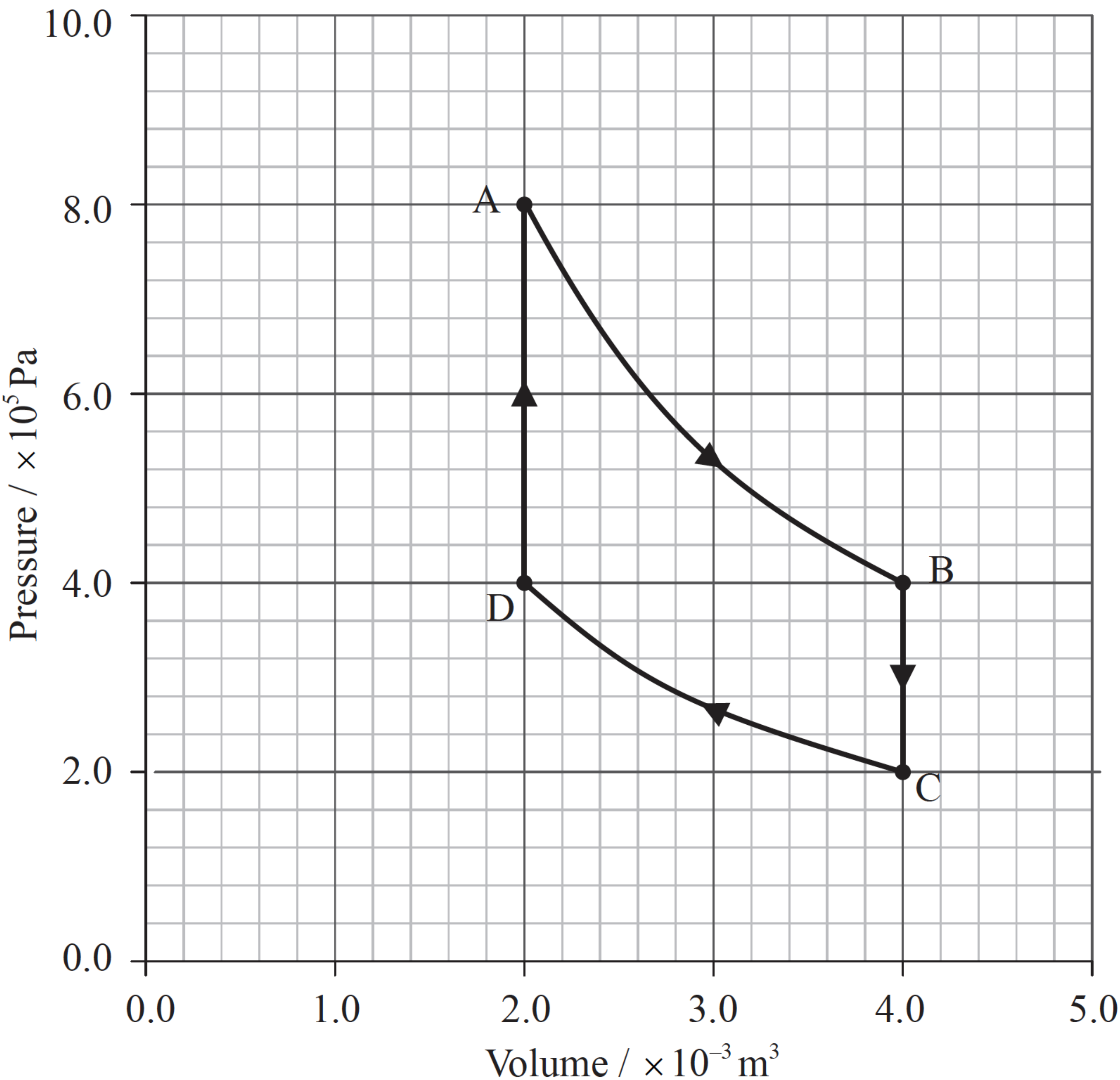
The temperature of the gas at point A is 85 °C. The gas can change its state to that of point C either along route ABC or route ADC.

a. Calculate the temperature of the gas at point C. [3]

b. Compare, without any calculation, the work done and the thermal energy supplied along route ABC **and** route ADC. [3]

Part 2 A heat engine

The piston of an engine contains a fixed mass of an ideal gas. During one cycle of the engine, the gas undergoes the thermodynamic processes shown below.



e. (i) State what is meant by an isothermal process. [4]

(ii) Show that process AB is isothermal.

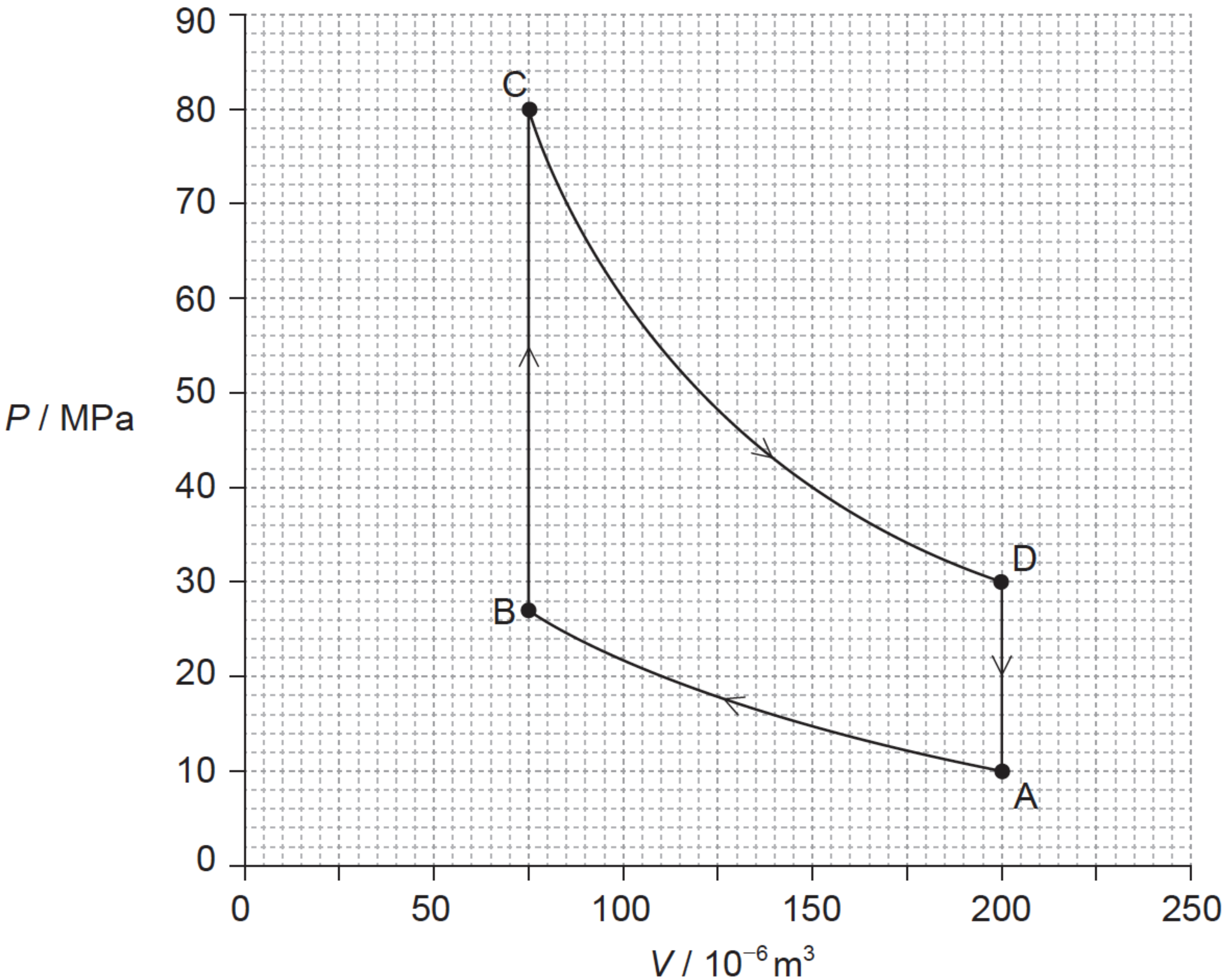
f. State the nature of process BC. [1]

g. During the cycle ABCD, the net work done by the gas is 550J. Calculate the net thermal energy absorbed by the gas. [2]

h. Explain why it is not possible for this engine, operating in this cycle, to be 100% efficient. [3]

This question is about an ideal gas cycle.

The *P*–*V* diagram shows a cycle ABCDA for a fixed mass of an ideal gas.



a. Estimate the total work done in the cycle. [3]

b. The change **AB** is isothermal and occurs at a temperature of 420K. Calculate the number of moles of gas. [3]

c. Identify and explain the change, if any, in the entropy of the gas when it has completed one cycle. [2]