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]

Markscheme

a. defined from the equation of state of an ideal gas $PV=nRT$;

all symbols (*PVnT*) correctly identified;

b. 390/391 K;

c. work done$=\left(P\Delta V=2.32\times10^5\times2.20\times10^{-3}=\right)510\text{J}$;

thermal energy$=(760+510=)\,1.27\times10^3\text{J}$;

*Award **[1 max]** if volume is taken as 3.6×10^{-3}, giving an answer of 1600 J.*

d. an adiabatic change is one in which no (thermal/heat) energy is transferred between system and surroundings / no energy enters/leaves system;

a rapid compression means that there is insufficient time (for energy transfer) / *OWTTE*;

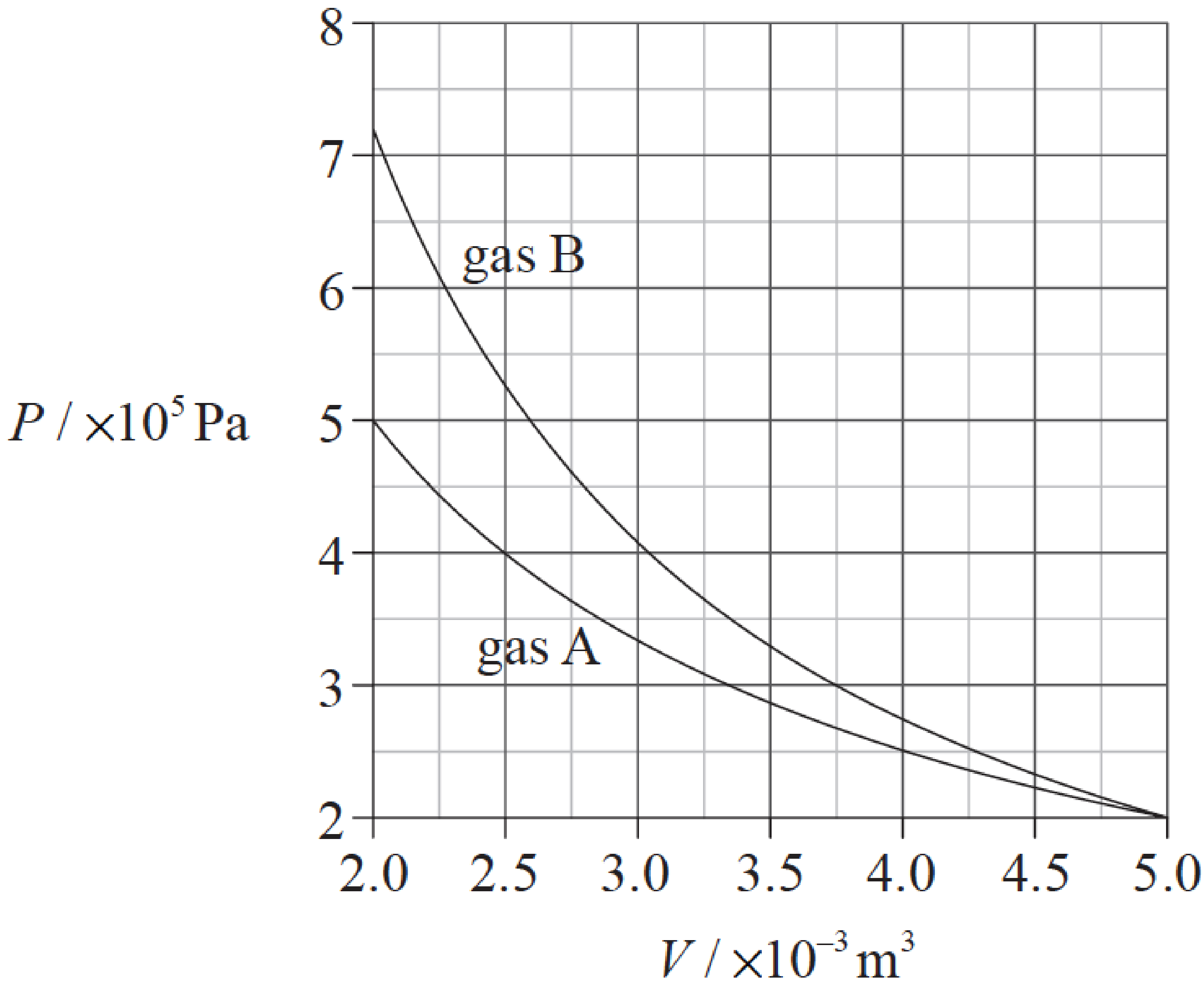
Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

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]

Markscheme

a. choice of two data points;

to show $P \times V$ constant for gas A / not constant for gas B;

b. identifies area between lines as work done;

counts squares (14 squares);

each square 12.5;

175 J; *(allow answers in the range of 150 to 200 J)*

c. $Q = \Delta U + W$ and $Q = 0$; *(both needed)*

so $\Delta U + W = 0$;

work done by gas is positive;

so ΔU decreases therefore temperature decreases;

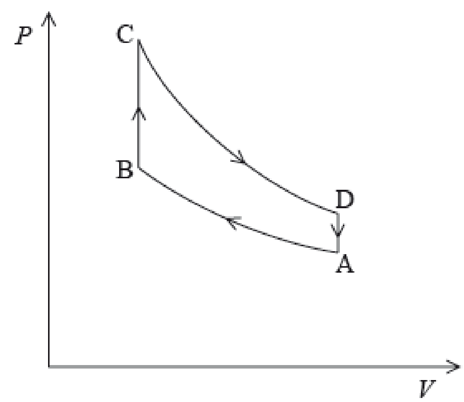
Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

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.

Markscheme

a. 535 (K) / 262 (°C);

b. constant volume change / isochoric / isovolumetric / *OWTTE*;

c. Q/thermal energy transfer is zero;

$\Delta U = -W$;

as work is done by gas internal energy falls;

temperature falls as temperature is measure of average kinetic energy;

d. work done is estimated by evaluating area;

inside the loop / *OWTTE*;

e. (i) 1.6×10^{-4} (litre);

(ii) one litre $= \left(\frac{1}{4\times18\times1.64\times10^{-4}} =\right)$ 87 s of travel;

$(87 \times 56) = 4.7$ (km);

Allow rounded 1.6 value to be used, giving 4.9 (km).

f. use of a kinematic equation to determine motion time $(= 12.5\ \mathrm{s})$;

change in kinetic energy $= \frac{1}{2} \times 1200 \times [28^2 - 12^2]\ (= 384\ \mathrm{kJ})$;

rate of change in kinetic energy $= \frac{384000}{12.5}$; } *(allow ECF of 16^2 from $(28 - 12)^2$ for this mark)*

31 (kW);

or

use of a kinematic equation to determine motion time $(= 12.5\ \mathrm{s})$;

use of a kinematic equation to determine acceleration $(= 1.28\ \mathrm{m\,s^{-2}})$;

work done $\frac{F\times s}{\text{time}} = \frac{1536\times250}{12.5}$;

31 (kW);

g. (i) $\text{force} = \frac{\text{power}}{\text{speed}}$;

2300 ***or*** 2.3k (N);

Award ***[2]*** *for a bald correct answer.*

(ii) resistive force $= \frac{2300}{4}$ ***or*** $\frac{2321}{4}$ $(= 575)$; *(allow ECF)*

so accelerating force $(2300 - 580 =)\ 1725\ (\mathrm{N})$ ***or*** 1741 (N);

$a = \frac{1725}{1200} = 1.44\ (\mathrm{m\,s^{-2}})$ ***or*** $a = \frac{1741}{1200} = 1.45\ (\mathrm{m\,s^{-2}})$;

Award ***[2 max]*** *for an answer of 0.49 (m s^{-2} (omits 2300 N).*

h. (i) centripetal force must be $< 6000\ (\mathrm{N})$; *(allow force 6000 N)*

$v^2 = F \times \frac{r}{m}$;

$31.6\ (\mathrm{m\,s^{-1}})$;

Allow ***[3]*** *for a bald correct answer.*

Allow ***[2 max]*** *if 4$\times$ is omitted, giving 15.8 (m s^{-1}).*

(ii) statement of Newton's first law;

(hence) without car wall/restraint/friction at seat, the people in the car would move in a straight line/at a tangent to circle;

(hence) seat/seat belt/door exerts centripetal force;

(in frame of reference of the people) straight ahead movement is interpreted as "outwards";

Examiners report

a. This simple gas law calculation was surprisingly badly done. Certainly similar questions have attracted better scores in previous examinations.

Common errors included the inevitable failure to work in kelvin, and simple arithmetic errors.

b. Most candidates were able to describe the constant volume nature of the change in question.

c. Many candidates scored full credit in a question that has been well rehearsed in previous examinations. The zero change in thermal energy transfer was common and many were able to deduce that ΔU is therefore equal to $-W$. This led immediately to a deduction of temperature decrease.

d. Almost all recognised that the work done was related to some area under the graph. In a small minority of cases the exact specification of the area was too imprecise to gain the second mark.

e. (i) It was common to see a correct value for the volume of fuel used though not a correct unit.

(ii) Many were able to arrive at a travel time for the fuel and therefore the distance travelled. However, routes were indirect and lengthy and few could see a direct way to the answer.

f. There were at least two routes to tackle this problem. Some solutions were so confused that it was difficult to decide which method had been used. Common errors included: forgetting that the initial speed was $12\ \mathrm{m\,s^{-1}}$ not zero, power of ten errors, and simple mistakes in the use of the kinematic equations, or failure to evaluate work done $=$ force $\times$ distance correctly. However, many candidates scored partial credit. Scores of two or three out of the maximum four were common showing that many are persevering to get as far as they can.

g. (i) Many correct solutions were seen. Candidates are clearly comfortable with the use of the equation force = power/speed.

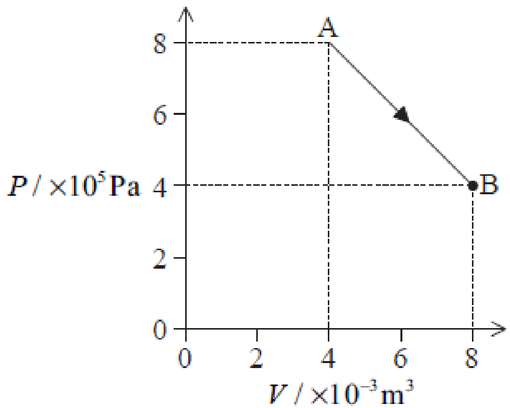
(ii) The method to be used here was obvious to many. What was missing was a clear appreciation of what was happening in terms of resistive force in the system. Many scored two out of three because they indicated a sensible method but did not use the correct value for the force. Scoring two marks does require that the explanation of the method is at least competent. Those candidates who give limited explanations of their method leading to a wrong answer will generally accumulate little credit. A suggestion (never seen in answers) is that candidates should have begun from a free-body force diagram which would have revealed the relationship of all the forces.

h. (i) The major problem here was that most candidates did not recognise that 1500 N of force acting at each of four wheels will imply a total force of 6 kN. Again, partial credit was available only if it was clear what the candidate was doing and what the error was.

(ii) Statements of Newton's first law were surprisingly poor. As in previous examinations, few candidates appear to have learnt this essential rule by heart and they produce a garbled and incomplete version under examination pressure. The first law was then only loosely connected to the particular context of the question. Candidates have apparently not learnt to relate the physics they learn to everyday contexts.

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).

Markscheme

a. realization that since *pV* = constant, the temperature must be the same *i.e.* 400 K / full calculation using gas law to get 400 K;

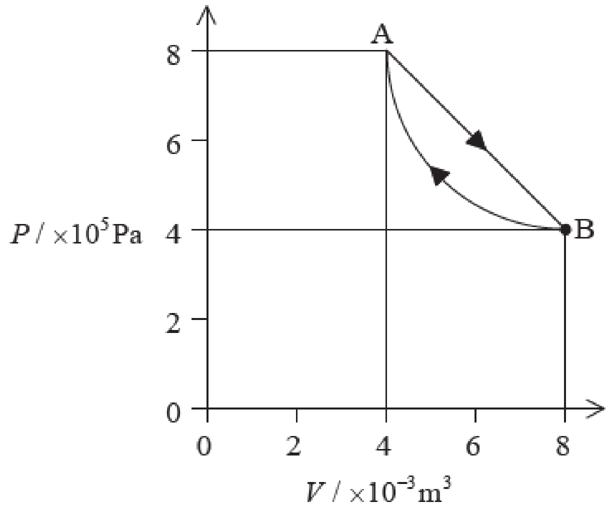
b. (i) work done is area under curve;

and this is $\left(\frac{4.0+8.0}{2} \times 4 \times 10^2\right) = 2400\text{J}$;

*Award **[2]** for correct bald answer.*

(ii) ($Q=\Delta U+W$ with) $\Delta U=0$;
so $Q=2400\text{J}$;
*Award **[0]** for correct answer with no or wrong argument.*

c. (i) curve under given straight line starting at B and ending at A;



(ii) it would be less;
since the work done would be less / area under curve is less (and $\Delta U = 0$);

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

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.

Markscheme

(i) Q: is the energy transferred between the system and surroundings;

W: work done on/by system;

(ii) Q transferred from reactor to gas;

no change in volume therefore $W = 0$;

internal energy of gas increases;

Q transferred from gas to surroundings therefore internal energy of gas

decreases;

(iii) entropy of the gas initially increases as energy transferred from the reactor;

entropy of the surroundings increases as energy transferred (from the gas);

entropy of gas decreases on cooling;

overall the entropy of the total system increases;

Examiners report

(i) The meanings of Q and W were often expressed poorly and incompletely.

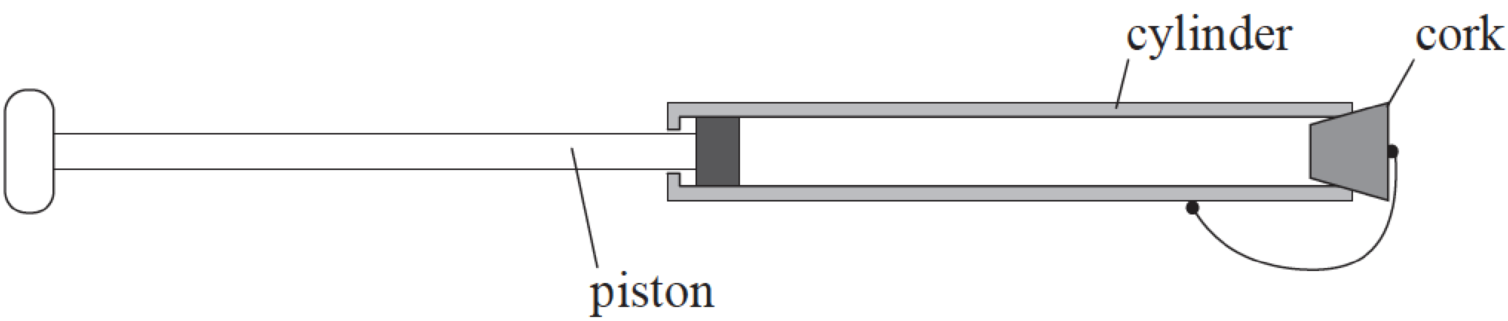
(ii) Some candidates are confused about the statement of the first law of thermodynamics and quoted the second. Others gave vague and uncreditworthy accounts that showed that they were not answering in the context of the reactor heat exchanger. There was no real attempt by most candidates to arrive at four points in the answer, despite the fact that there are two exchanges going on in the reactor.

(iii) As in part (ii) some candidates did not focus on the context intended. The failure to identify all exchanges and entropy changes was common as in part (ii).

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 $6.0\times10^{-4}m^{3}$.

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]

Markscheme

a. $n=\frac{pV}{RT}=\frac{1.1\times10^5\times6.0\times10^{-4}}{8.31\times290}$;

0.027;

b. (i) calculate *pV* correctly for both states: 66 and 76; } *(do not penalize 66 k/K and 76 k/K as k may be a constant)*

isothermal change would mean that $p_1V_1=p_2V_2$;

so not isothermal

(ii) no heat/thermal energy transferred;
(because change/compression) occurs (too) quickly/fast; [2]

(iii) $Q=0$;
$W=-15$; *(minus sign is required)*
so $\Delta U=(+)15$J; } *(symbols must be defined)*
(allow ECF from second marking point)

(iv) number of air molecules$=0.0274\times6.0\times10^{23}(=1.64\times10^{22})$;
9.13×10^{-22}J;

c. entropy is a property that indicates degree of disorder in the system / *OWTTE*;

gas occupies a smaller volume; *(do not allow "compressed")*

entropy of gas/air in toy decreases because more ordered;

energy reaches surroundings/cylinder / entropy cannot decrease;

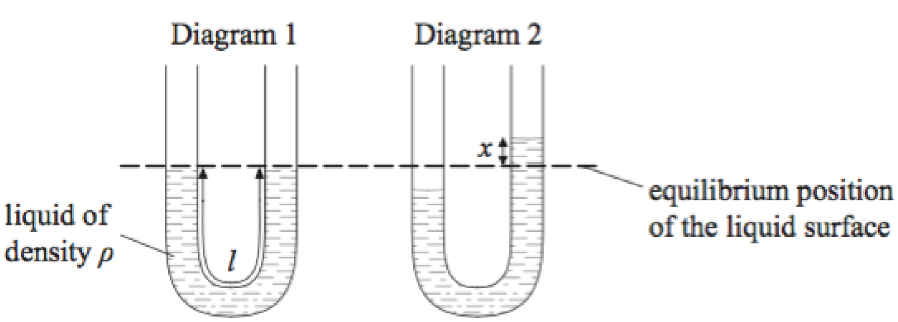
so entropy of surroundings/cylinder increases; } *(do not allow ECF from "entropy of gas increases")*

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

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.

Markscheme

b. (i) the amplitude of the oscillations/(total) energy decreases (with time); because a force always opposes direction of motion/there is a resistive force/ there is a friction force;

Do not allow bald "friction".

(ii) the displacement and acceleration/force acting on (the surface); are in opposite directions;

(iii) $\omega = \sqrt{\frac{2g}{l}}$;
$T = 2\pi\sqrt{\frac{0.32}{2\times9.81}}$;
=0.80s;

d. (i) wave reflects at ends (of string);

interference/superposition occurs (between waves);

regions of maximum displacement/zero displacement form (that do not move);

one region of max displacement/antinode forms at centre with zero displacement/node at each end; {*(allow these marking points from clear diagram)*

(ii) the waves (in a string) are transverse and vibrate only in one plane;

light waves are transverse electromagnetic waves;

(and) for polarized light the electric field vector vibrates only in one plane;

Examiners report

b. Candidates had some uncertainty in discussing the negative sign in the SHM equation for the U-tube example. They were unclear about the terms in the equation and the relative direction of the vector quantities concerned.

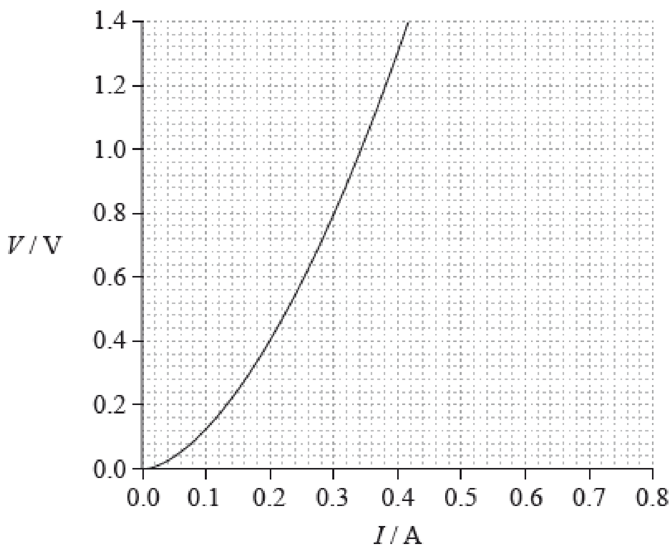
d. (i) Although there were many suggestions that the wave is reflected at one end of the string and that this interferes in some way with the incident wave to produce the standing wave these were generally weak and incomplete. Some candidates focussed entirely on the shape of the standing wave (not really the question). It was rare to see 3 marks awarded; 2 was more common.

(ii) Candidates were vague as to the nature of polarized light (a clear description in terms of the field vectors was required), as to the description of the travelling wave on the string, and as to the way in which it could be used. Many will have seen the demonstration in the laboratory but could not describe it with clarity.

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.

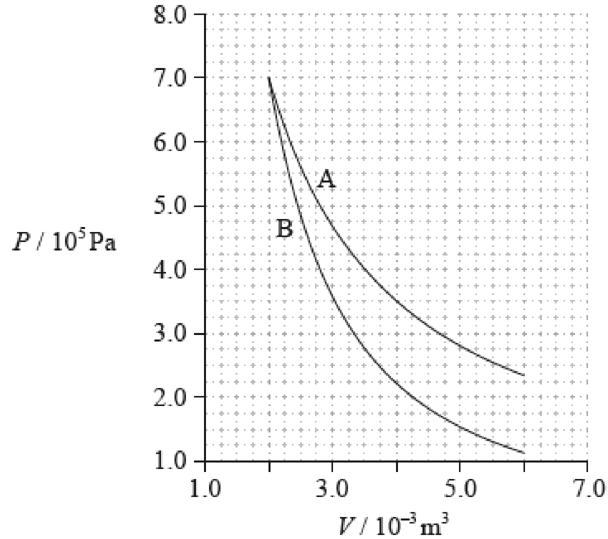
Part 2 Expansion of a gas

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]

Markscheme

b. charge carriers/electrons move through cell;

transfer energy to the components of the cell (which is not therefore available to external circuit);

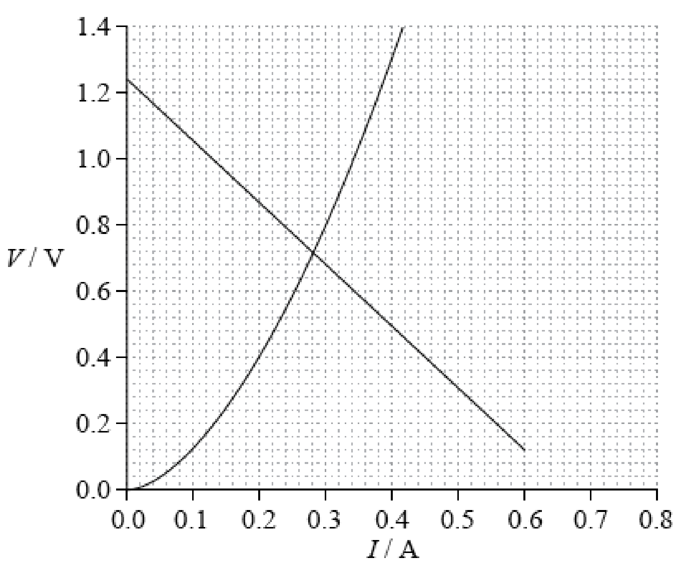
energy dissipated in cell equivalent to dissipation in a resistance;

causes potential difference of cell to be less than its emf;

d.i. straight line of negative gradient; *(allow any straight line of negative gradient)*

intercept at $1.25\text{ V } (\pm 0.05)$ and position/gradient as shown;

Watch for ECF from (c)(iii).



d.ii. uses a point at which lines intersect;

reads correct current value from their own graph;

$0.28\text{A} \pm 0.1\text{A}$; *(award for correct answer only)*

e. PV is a constant for A / B is a steeper curve / final temperature/pressure lower for B than A;

(hence) B;

f. number of small squares below $\text{A} = 180 \pm 20$;

area of 1 square $= 6.25 \text{ J}$;

adds additional 64 squares below false origin;

answer within the range of 1400 to 1650 J; } *(allow ECF for an area that excludes the area below the false origin – giving an answer within the range of 1000 to 1250 J)*

*Award **[2]** for a mean P of* $4.65 \times 10^5 \times \Delta V$ *of* 4×10^{-3} *giving an answer of 1860 (J).*

Accept working in large squares (= 16 small squares) using equivalent tolerances.

g. no thermal energy enters or leaves / $Q = 0$;

work done by the gas / W is positive;

so internal energy decreases / ΔU is negative;

temperature is a measure of internal energy and so temperature falls;

Examiners report

b. This was a 3 mark question about internal resistance, so reasonable detail was expected. Candidates needed to refer to electrons/charge dissipating energy in moving through a cell and the effect on terminal potential difference.

d.i. Very few correct answers were seen. The equation of the line required is $V = E - Ir$. Hence a line of negative gradient $(-1.9 \ \Omega)$ was required with a y intercept of 1.24 V.

d.ii. If a candidate drew any kind of line, ECF was used when the coordinate of the intersection of the two lines was used to determine a current.

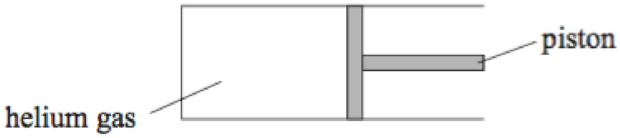
e. Most candidates were able to identify B as the adiabatic – either by referring to the gradients or lower pressures and temperatures compared to A, or by showing PV was constant for A but not B.

f. This was a 4 mark question and so candidates needed to give a detailed response. Many stated the 1st law, identified the three symbols and explained the change in each during an adiabatic expansion. Others were far less systematic. Most eventually predicted that temperature would decrease, but lost marks in their explanation.

g. This was a 4 mark question and so candidates needed to give a detailed response. Many stated the 1st law, identified the three symbols and explained the change in each during an adiabatic expansion. Others were far less systematic. Most eventually predicted that temperature would decrease, but lost marks in their explanation.

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]

Markscheme

a. (i) use of $R = \frac{pV}{nT}$; *(award mark if correct substitution seen)*

$\left(\frac{5.2\times10^{-3}\times1.0\times10^5}{0.23\times290}\right) = 7.8\text{JK}^{-1}\text{mol}^{-1}$; (accept Pa m^3 mol^{-1} K^{-1})

(ii) the gas is ideal;

b. constant temperature required; *(do not allow "isothermal")*

a slow compression allows time for (internal) energy to leave gas / *OWTTE*;

c. (for adiabatic change) *Q*=0;

W is positive / work is done by the gas;

ΔU =–*W* so *ΔU* is negative;
(*T* is a measure of *U* therefore) *T* less than 290K***;***

Examiners report

a. (i) Very many candidates were able to arrive at a value for R from the data given. Some however fudged their answer to arrive at the accepted value of 8.31! It was common to see a unit of Pa m3 K-1 mol-1 which, while it is acceptable, shows that the candidate quoting it has little sense of the true meaning of R.

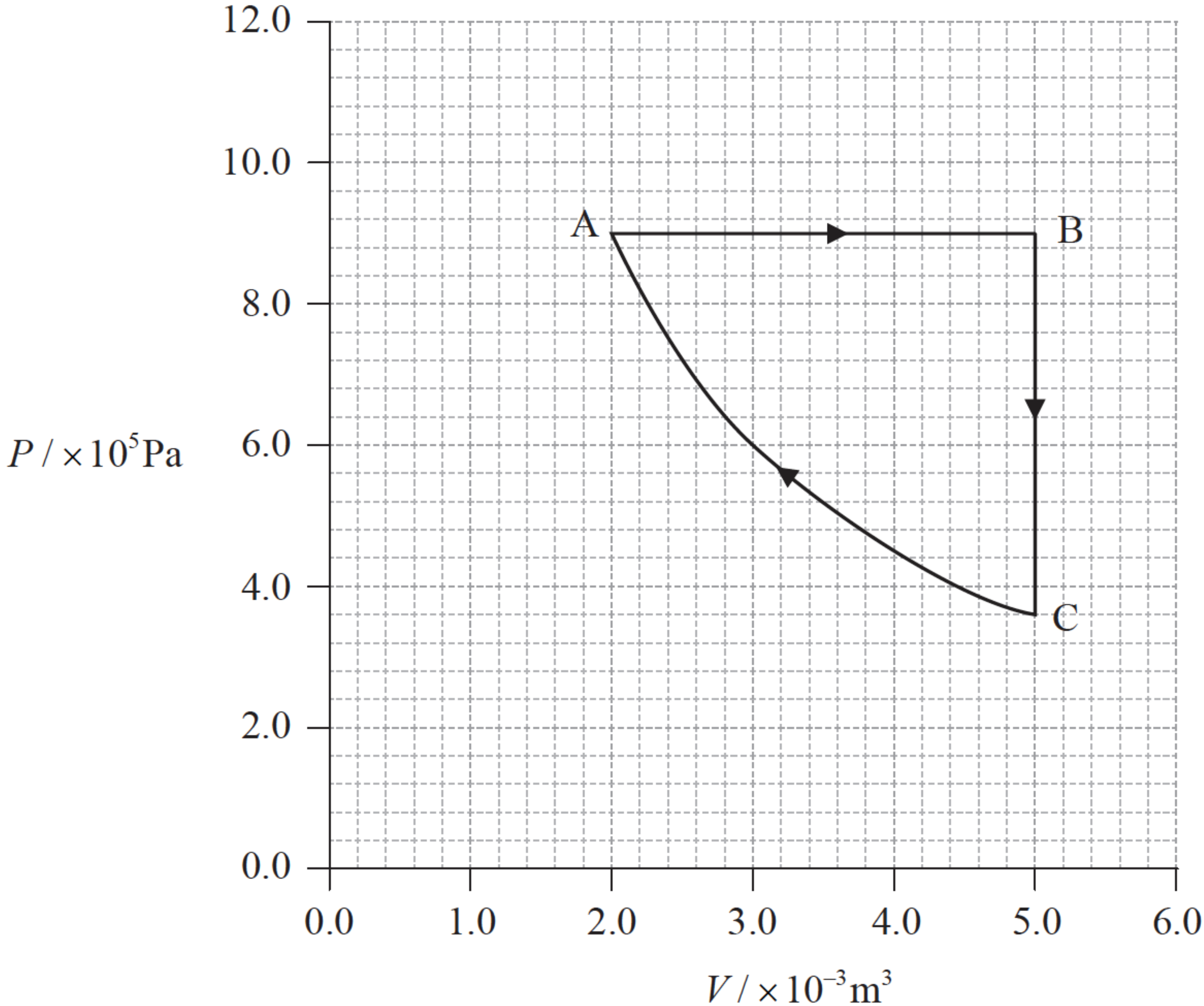
(ii) Most recognized that the gas has to be ideal for the calculation in (i) to be carried through.

b. Many were able to say that the temperature must not change (isothermal). Too many simply repeated the word "isothermal" from the stem, this gained no credit. However, only a few stated with clarity that the system needs time to allow the energy to leak out *to the surroundings.*

c. This part was done well, unlike similar questions in recent examinations. Candidates can explain the direction of energy flow and its consequences for the system in terms of the first law of thermodynamics. However, too many failed to use the first law and wrote in general terms about pressure and volume changes.

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.

Markscheme

a. process AB: isobaric;

process BC: isochoric / isovolumetric;

process CA: isothermal;

b. use of $\frac{V_2}{V_1} = \frac{T_2}{T_1}$;

to give 750 K;

c. $W = (P\Delta V = 9 \times 10^5 \times [5-2] \times 10^{-3} =) 2700$;

$Q = \Delta U + W = 4100 + 2700 = 6800$J;

d. (i) same number of molecules occupy smaller volume, so disorder and hence entropy decrease;

(ii) heat flows from gas to surroundings, so temperature of surroundings increases, so entropy increases;

(iii) from second law, entropy of universe increases during any process;

*Award **[0]** for simple statement of entropy increases/decreases.*

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

Part 2 Properties of a gas

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

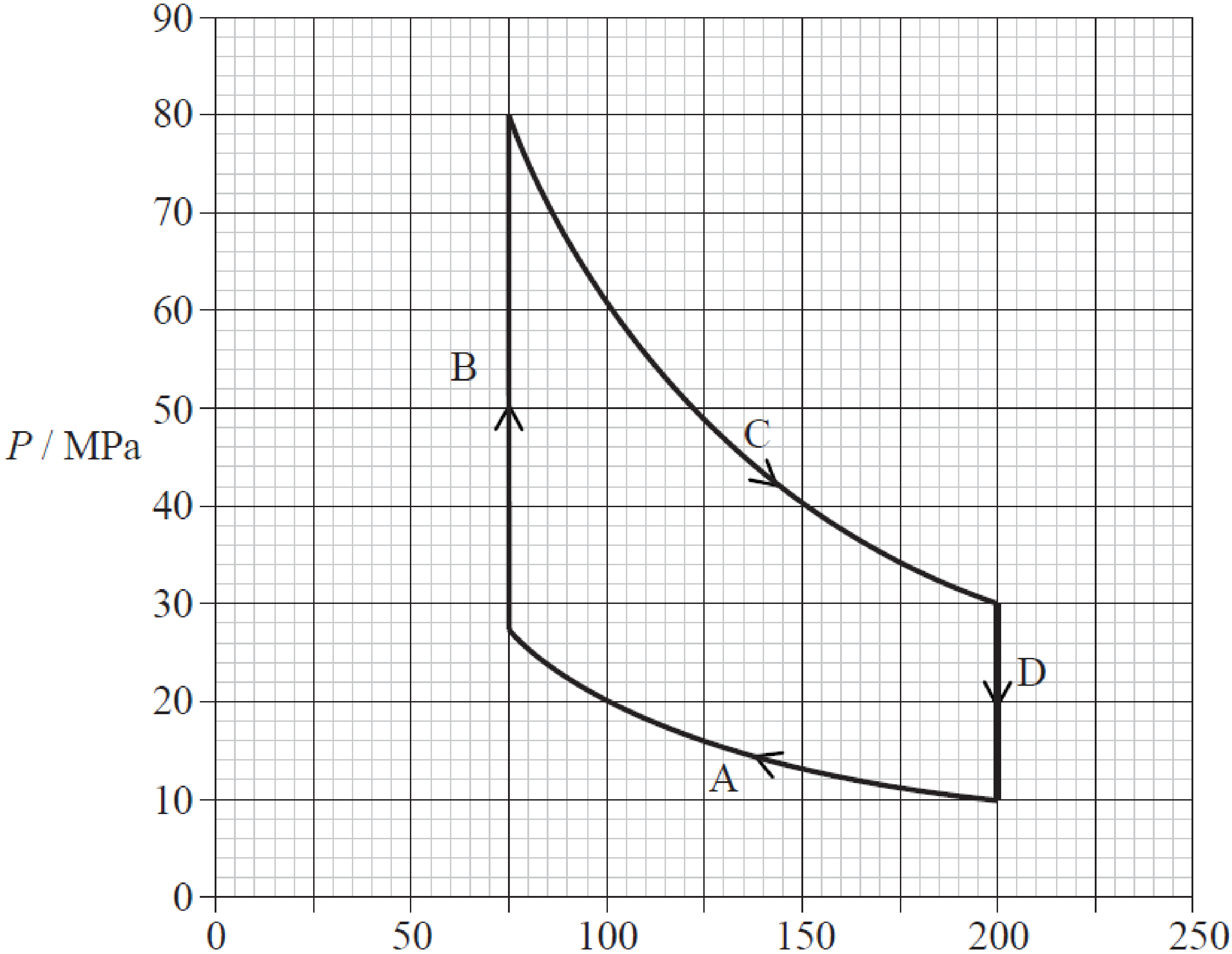
Thermal energy: . . . .

. . . .

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**.

Markscheme

a. *(Q)* energy transferred between two objects (at different temperatures);

(U) (total) potential energy and (random) kinetic energy of the molecules/particles (of the gas);

b. (i) use of area within cycle;

each large square has work value of 250 (J);

estimate (16 x 250=)4000 (J); (allow 3600 – 4100)

*Award **[3]** for same outcome with small squares of area 10 (J).*

(ii) (work is done by the gas because) area under expansion is greater than that under compression/pressure during expansion is greater than during compression;

(iii) clear attempt to compare two *PV* values;
evaluate two *PV* values correctly *eg* 75 x 80= 6000 and 200 x 30= 6000;

(iv) use of *PV* =*nRT* or equivalent;
1350/1330 (K);

(v) both changes are isochoric/isovolumetric/constant volume changes;
B: temperature/internal energy increases, D: temperature/internal energy decreases;
B: thermal energy/heat input (to system), D: thermal energy/heat output (from system);
B: pressure increases, D: pressure decreases;

Examiners report

a. Few candidates were able to explain thermal energy was the energy transfer between two objects at different temperatures. Many knew the definition of internal energy but a high percentage omitted to mention the potential energy (probably assuming that the gas was ideal).

b. (i) Many candidates appeared to attempt to calculate area without actually saying what they were doing; although this was obvious when they referred to the area of a square, in many case it was not obvious and marks were lost when the candidates technique produced an answer out of tolerance. In examples like this there will be a reasonable tolerance for the area and it is not expected that candidates will waste considerable time in counting the small squares.

(ii) Although some candidates were aware that a clockwise cycle applies to net work done by the gas, this does not explain the choice. Simply saying that the area under the expansion was greater than the area under the compression was all that was needed.

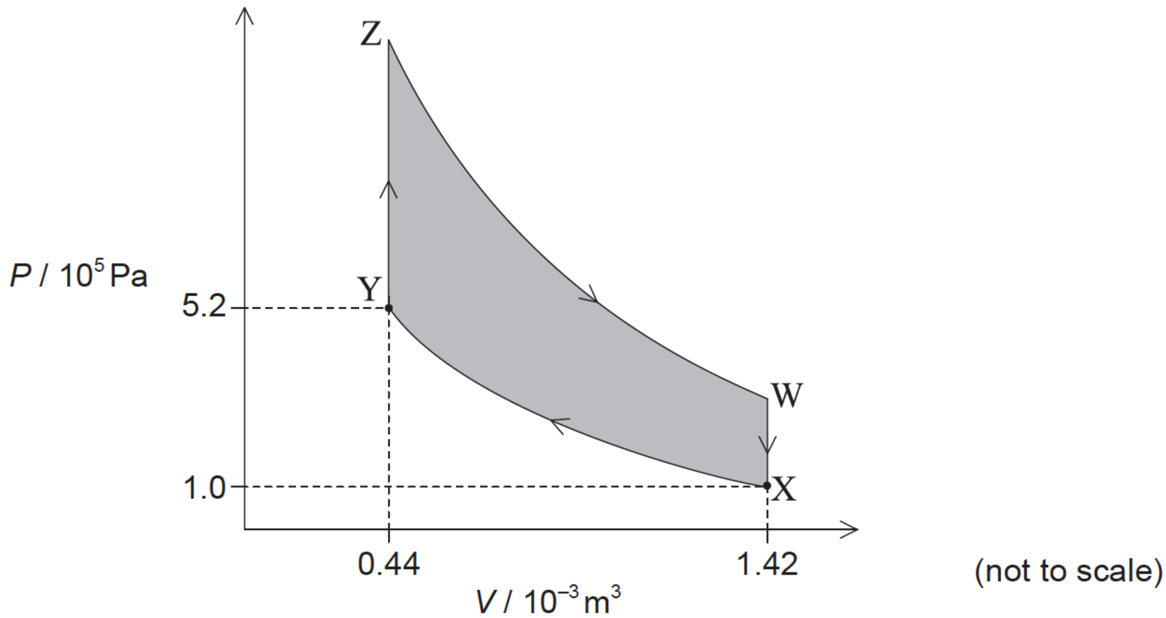
(iii) This part was mostly well done by candidates. It is accepted, in line with SL A1, that showing constancy of two PV values does not prove that the change is isothermal; however in terms of deducing that the change is isothermal this technique is fine – that is, the candidates are told that it is isothermal and they are simply illustrating that this is the case. Often examiners will expect three values to be taken in questions such as this.

(iv) This part was well done by those many candidates who used any appropriate variant of the ideal gas equation to calculate the temperature.

(v) The large majority of candidates did well here although a minority were deducted marks when they used contradictory statements such as isochoric and compression or expansion.

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]

Markscheme

e. vertical line identified;

Do not penalize candidate who identifies both vertical lines.

*Award **[0]** if vertical and another line identified.*

f. *at point X:* $nR = \frac{1.42\times1\times100}{310} = 0.4581$;

at point Y: $T = \left(\frac{0.44\times5.2\times100}{0.4581} =\right) 500\text{K}$

*Award **[2]** for a bald correct answer.*
Must be clear what units are here, ºC unacceptable unless converted correctly.

g. (i) (net) work done by engine in one cycle; } *(must imply "by engine" and "one cycle")*

(ii) efficiency=$\frac{610}{1300}$;

0.47 ***or*** 47%;

*Award **[2]** for a bald correct answer.*

*Award **[1]** for* $\frac{610}{(610+1300)}$*=0.32.*

*Award **[0]** for any fraction that would exceed 1 even if later fudged.*

*Award **[0]** for efficiency* $= \frac{T_C - T_H}{T_H}$ *=38%, question does not imply that this is a Carnot cycle.*

(iii) it has gone to the surroundings / it is dissipated;

it cannot be used for further useful work;

h. $\Delta Q = 0$;

210 (J); *(do not accept negative sign)*

Examiners report

e. [N/A]

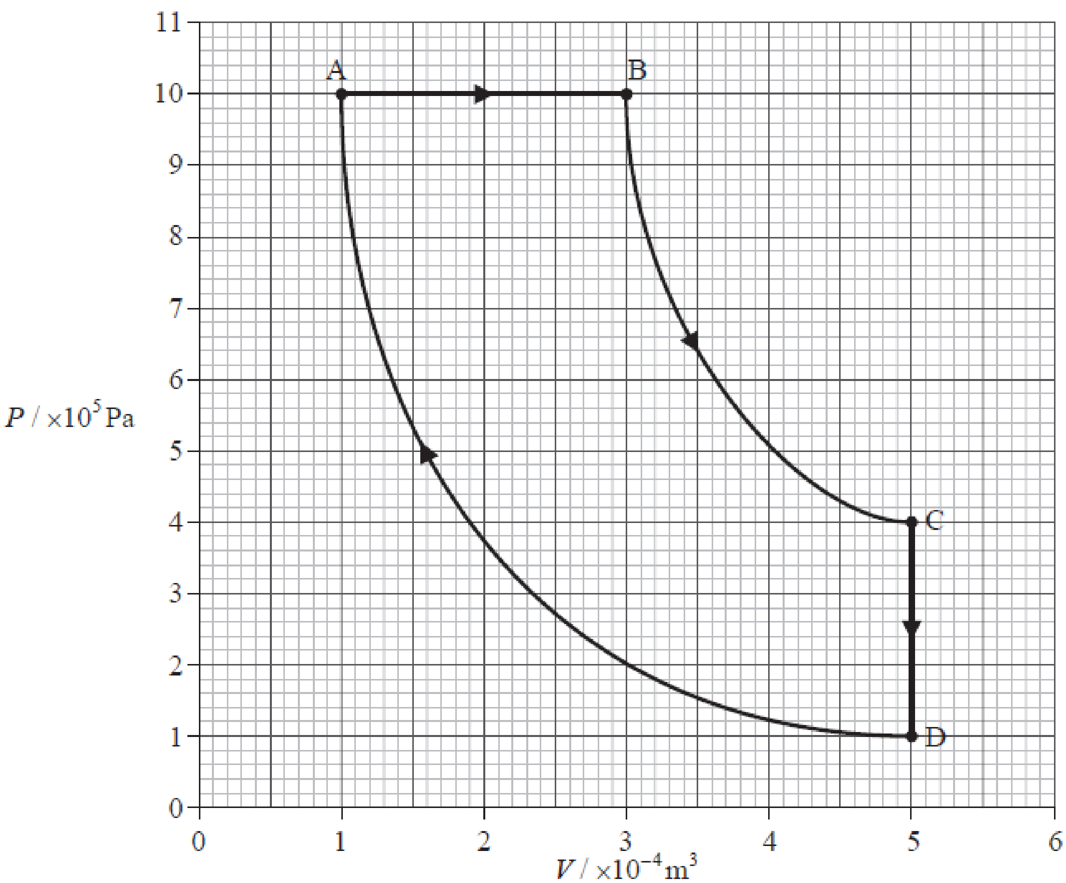
f. [N/A]

g. [N/A]

h. [N/A]

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]

Markscheme

a. (i) low pressure;

high temperature;

(ii) no thermal/heat energy is transferred (in change of state);
Allow "heat energy" but not "heat".

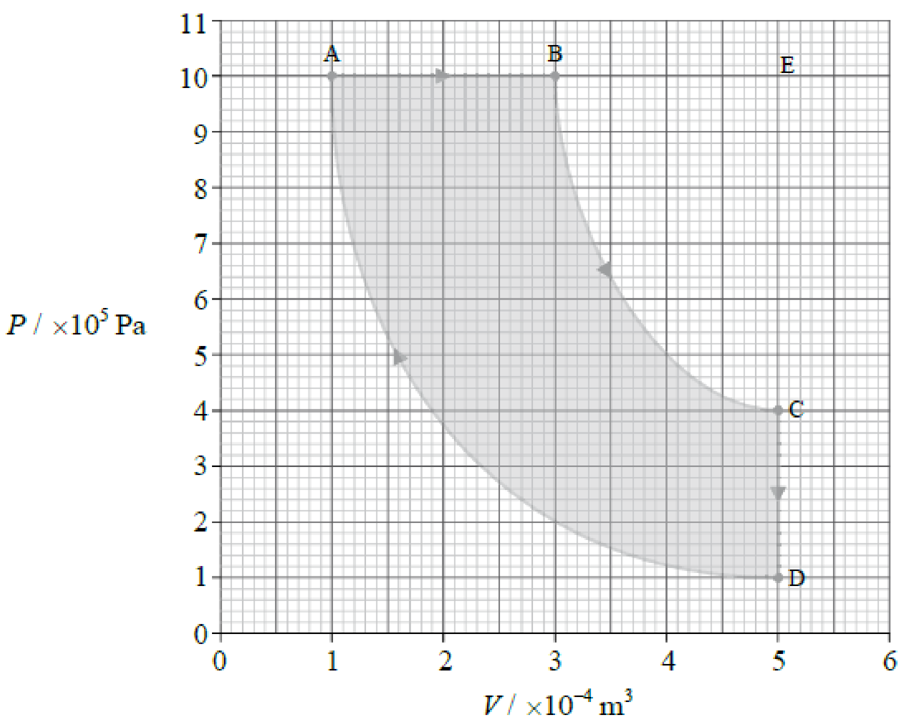
b. work is done (by the gas) because there is an increase in volume/gas expands;

so W is positive;

ΔU is greater than zero (because P is constant and V increases);

from first law $Q=\Delta U+W$ means that Q is positive which means energy transferred into gas;

c.



total work done = enclosed area / number of large squares ~40(±5);
1 square=5 J;
work done=200J (±25) J;

Examiners report

a. (i) Some candidates simply repeated the information they had already supplied in A4(a) without thinking the problem through afresh. The correct ideas of low pressure and high temperature were commonly seen in scripts.

(ii) Many recognized that adiabatic changes involve no energy interchange. Those who talked about no exchange of heat were penalized. The bald term “heat” is not awarded credit in this examination.

b. This was often well done with perhaps a third of the candidates gaining full or near-full marks for recognition of the work done and a deduction from this of the sign of ΔU and W.

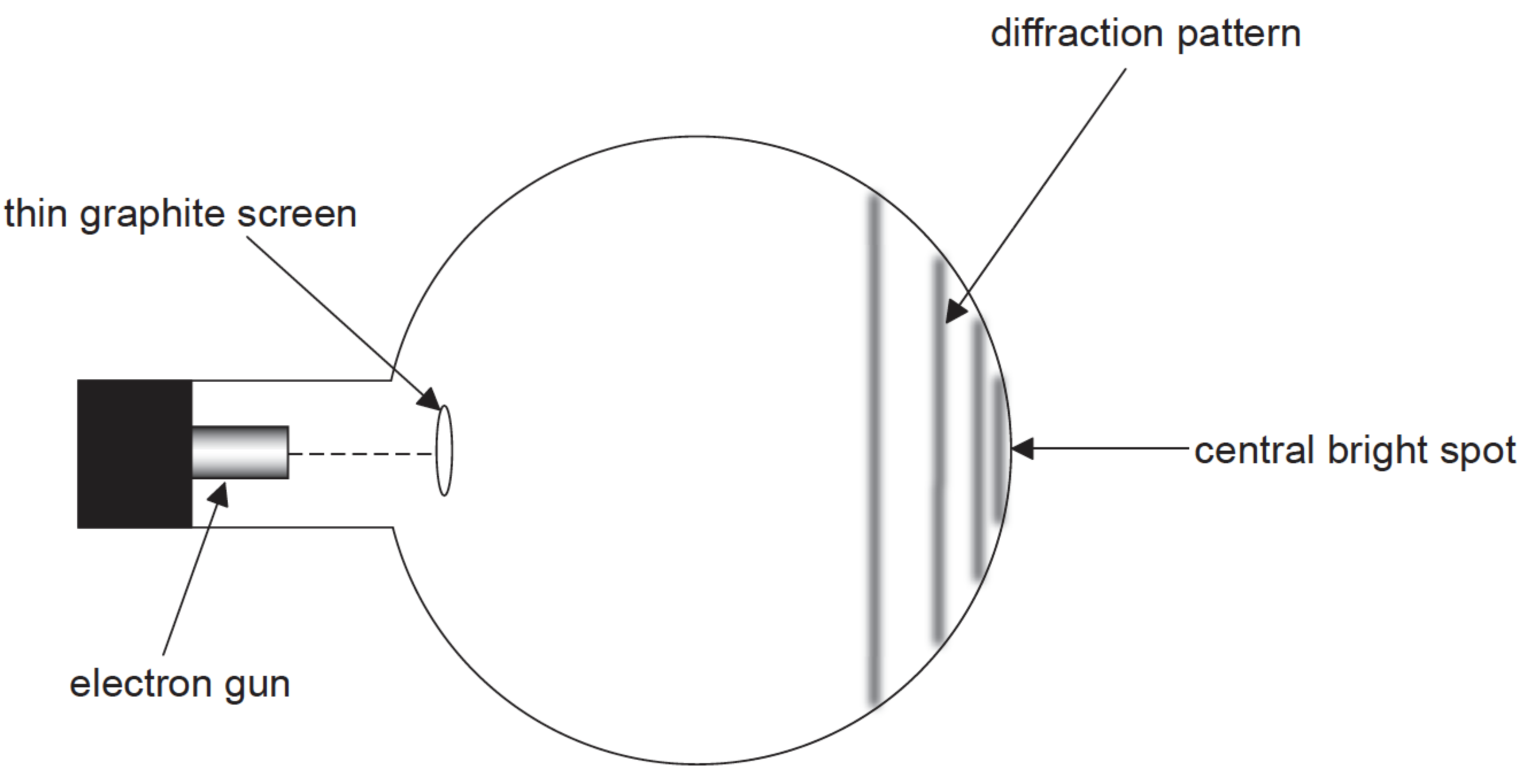
c. Although about half were able to arrive at a close estimate of the work done in the cycle, sometimes explanations were brief and obscure. A string of numbers without explanation does not endear itself to the examiners who can only rarely give credit to partial solutions if it is not clear what ideas are in use or where the data is coming from.

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 0°C are dropped into a container of water at a temperature of 22°C. 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 $3\times10^{16}ms^{-2}$.

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]

Markscheme

b. (i) use of $M\times4.2\times10^{3}\times\Delta\theta$;

$ml = 75\times10^{-3}\times3.3\times10^{5}$ / 24750 J;

recognition that melted ice warms and water cools to common final temperature;

3.4°C;

(ii) work done on water by dropping cubes / negligible work done;
W negative or unchanged;
water gives thermal energy to ice;
Q negative;
water cools to a lower temperature;
ΔU negative / U decreases;

c. bright and dark rings/circles / circular fringes;

maximum and minimum / constructive and destructive;

mention of interference / mention of superposition;

link to interference being characteristic of waves;

d. (i) ($p=m_e v=$) 3.28×10^{-23}Ns;

$$\lambda = \left(\frac{\mathrm{h}}{\mathrm{p}} = \frac{6.63\times10^{-34}}{3.28\times10^{-23}} =\right) 2.02 \times 10^{-11}\mathrm{m};$$

(ii) $E = \left(\frac{\Delta V}{\Delta x}\right) = \frac{3.7\times10^{3}}{22\times10^{-3}} \left(= 1.68 \times 10^{5}\right) \mathrm{Vm}^{-1};$
$F = (Eq) = 1.68 \times 10^{5} \times 1.6 \times 10^{-19} = \left(2.69 \times 10^{-14}\right) \mathrm{N};$
$a = \frac{F}{m} = \left(\frac{2.69\times10^{-14}}{9.11\times10^{-31}}\right) = 2.95 \times 10^{16}\mathrm{ms}^{-2};$

or

use of appropriate equation, eg $v^2 = u^2 + 2as$;

correct substitution (ignoring powers of ten);

$a = 2.95 \times 10^{16}\ ms^{-2}$

e. square of amplitude (of wavefunction);

(proportional to) probability of finding an electron (at a particular point);

f. relates position to momentum (or velocity);

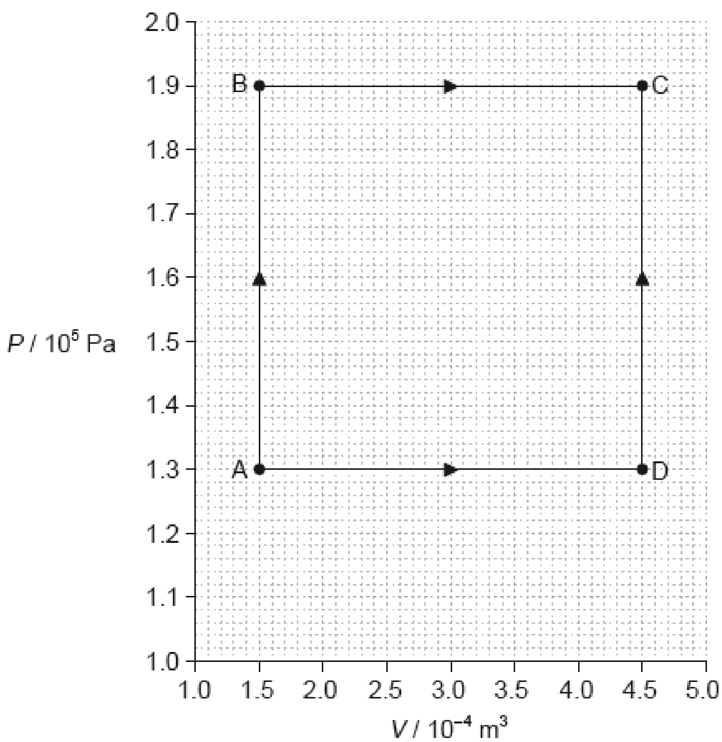
large uncertainty in momentum / most information on momentum is lost;

Examiners report

b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]

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]

Markscheme

a. use of $\frac{PV}{T}$ = constant ***or*** use of $T \propto PV$ ***or*** via intermediate calculation of n in $PV = nRT$;

$\frac{1.95}{358} = \frac{8.55}{T_c}$ ***or*** $n = 6.55 \times 10^{-3}$ (mol); } *(allow power of ten omission provided same omission on both sides)*

1570 K ***or*** 1300 °C;

*Award **[3]** for a bald correct answer ignoring small rounding errors.*

*Omitting conversion to Kelvin yields answer of 373 – award **[2 max]** as one error.*

*Award **[1 max]** if 273 subsequently added (to give 646).*

b. same temperature change so same change in internal energy/ΔU;

work done along ABC is larger/ADB is smaller because area under ABC is greater than area under ADC/ΔV same in both, P greater for ABC so $P\Delta V$ also greater for ABC;

because $\Delta Q = \Delta U + W$ thermal energy transferred is greater for route ABC/smaller for route ADB;

Must see reference to first law for MP3.

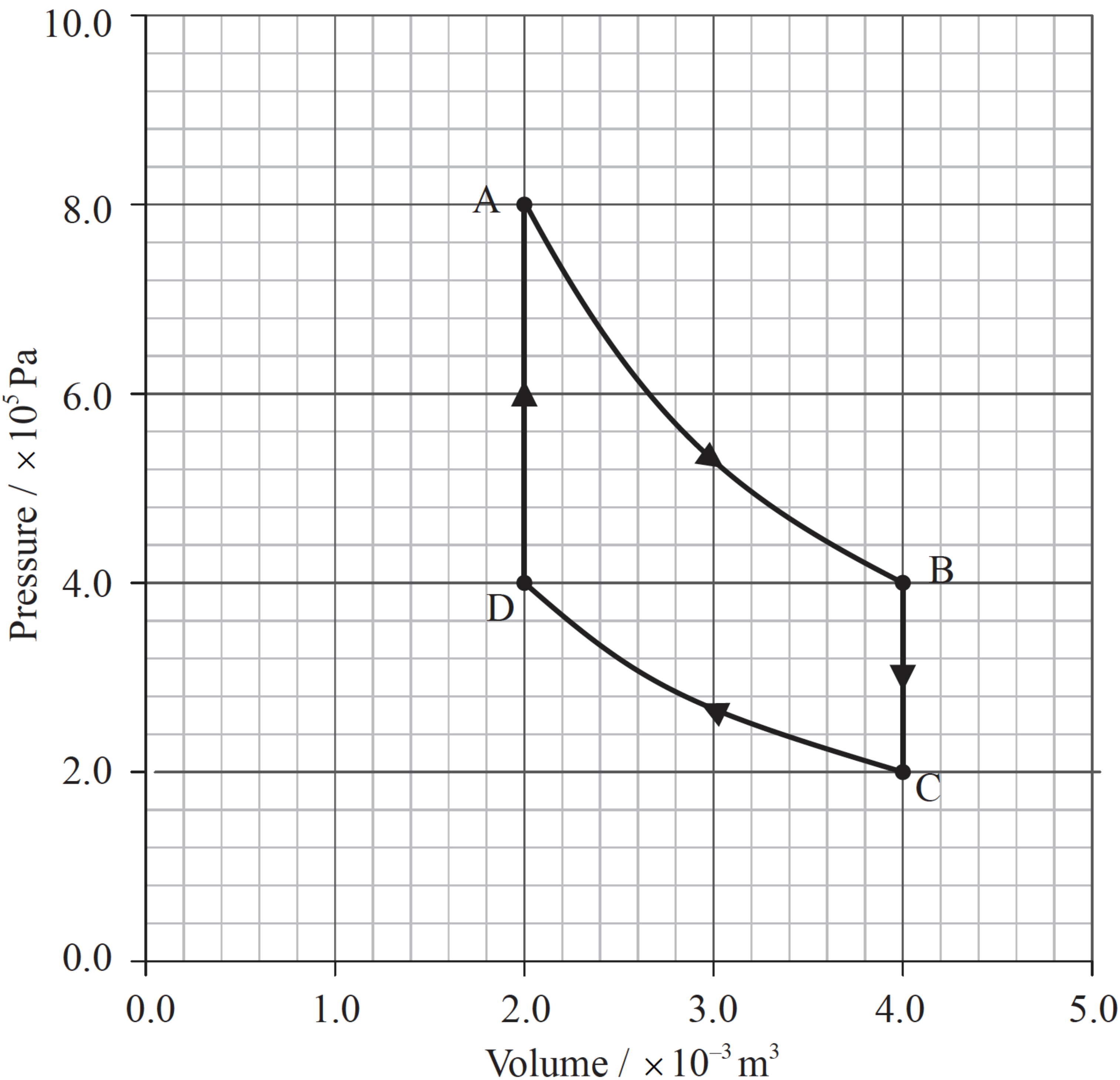
Examiners report

a. It is sad that many young physicists at this level cannot negotiate their way correctly through a straightforward gas-law calculation. As usual, many failed to convert from degree Celsius to Kelvin before carrying out the numerical manipulation. This was an excellent way to lose marks.

b. A good number were able to give answers to parts of this question but few could pull all the strands together convincingly. Frequent omissions were: to show that the internal energy changes are identical because the endpoint temperatures are the same, and to use the first law to confirm the final linking statement.

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]

Markscheme

e. (i) a process in which temperature remains constant;

(ii) calculation to show that pV=16(×10^2) at any point from A to B;
calculation to show that pV=16(×10^2) at any other point from A to B;
pV is constant;

f. isochoric / isovolumetric / occurs at constant volume;

g. $\Delta U = 0$;

Q=W=550(J);

h. the gas/system must return to original conditions (*P*, *V*, and *T*);

(to do that) some of the thermal energy absorbed by gas must be given off to the surroundings;

hence not all thermal energy absorbed by gas can be converted to work;

it is the second law of thermodynamics;

Examiners report

e. ei) Most recognized the meaning of isothermal.

eii) The calculations were successfully done but some candidates missed a concluding statement.

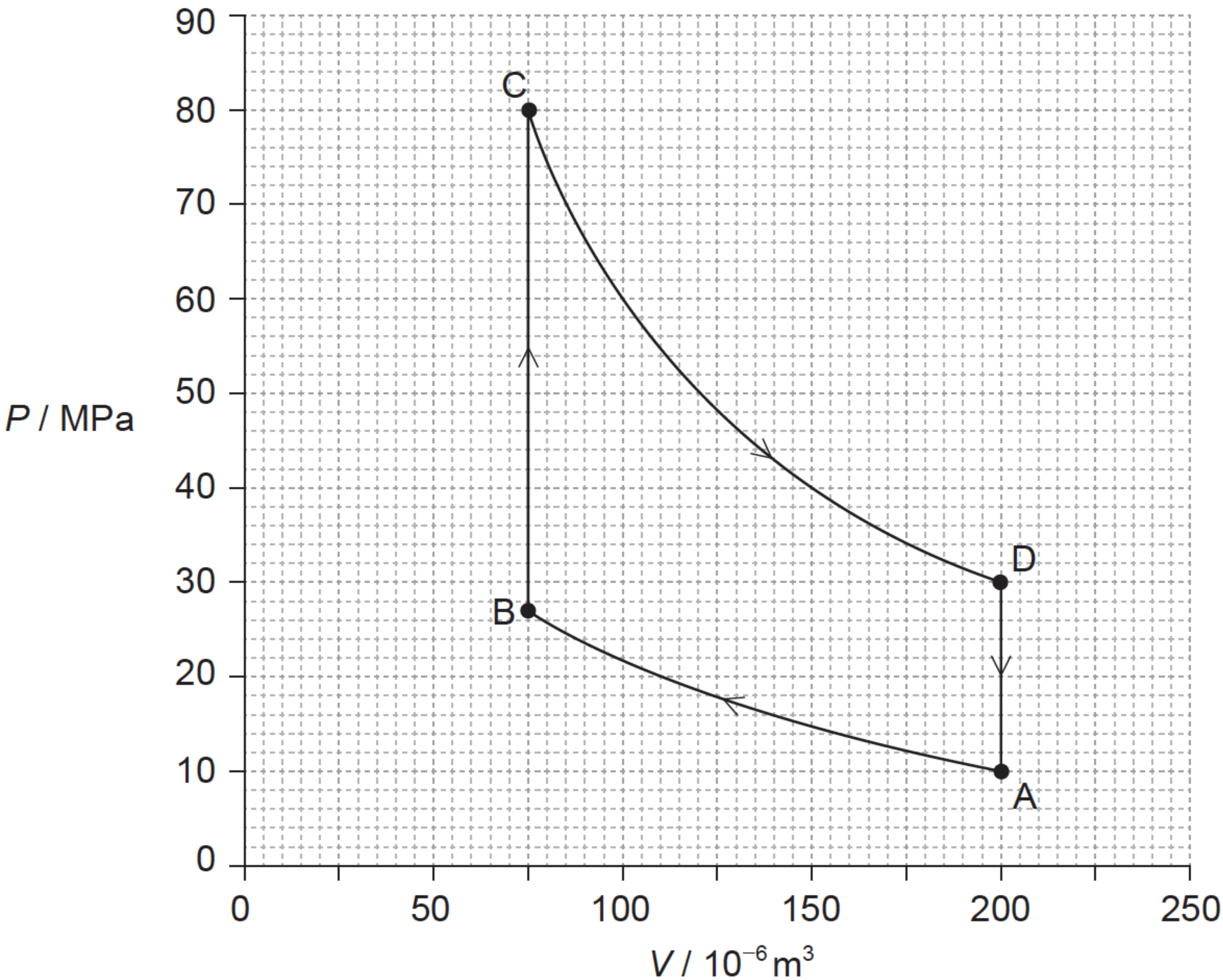
f. This was well answered.

g. A significant number attempted a calculation based on the area under the graph on the previous page.

h. Many were able to relate this to the second law of thermodynamics and recognized that some of the thermal energy was given off to the surroundings.

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]

Markscheme

a. use of area under the curve;

each (1 cm × 1 cm) square has energy of 250 J ***or*** each small square has energy of 10 J;

estimate (14 to 16 × 250) = 3500 to 4000 J;

b. clear use of value on AB; (*must see correct values*)

use of $PV = nRT$;

0.56 to 0.60 mol;

c. entropy unchanged;
gas returned to original state;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]