Access Tuition

A-Level Physics

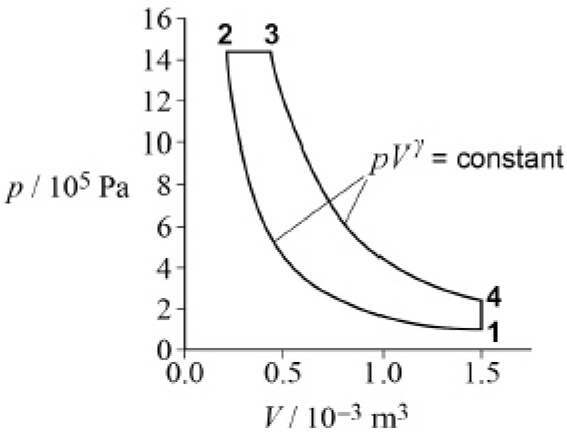
First Law of Thermodynamics

Question Paper

Time available: 65 minutes
Marks available: 46 marks

1. **Figure 1** shows the p–V diagram for an idealised diesel engine cycle. In this cycle a fixed mass of air is taken through four processes **1** → **2** → **3** → **4** → **1**.

Figure 1



(a) Which statement about this cycle is true?

Tick (✓) the correct answer.

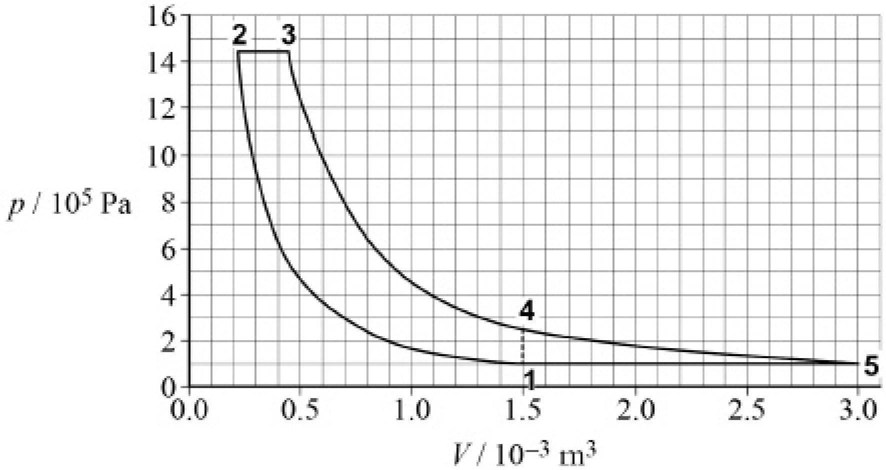
Work is done by the air in process **4** → **1**.	☐
Energy is supplied to the air by heating only in process **2** → **3**.	☐
The temperature of the air rises in process **3** → **4**.	☐
The area enclosed by the loop **1** → **2** → **3** → **4** → **1** is the power output of the cycle.	☐

(1)

(b) The cycle in **Figure 1** may be modified by allowing the air to continue to expand adiabatically from state **4** until it is at atmospheric pressure at state **5**.

Figure 2 shows the modified cycle.

Figure 2



The expansion stroke **3** → **5** is now longer than the compression stroke **1** → **2**. Process **5** → **1** takes place at constant pressure.

It has been claimed that, compared to the cycle in **Figure 1**, the modified cycle of **Figure 2** gives

A an increase in work done per cycle of 130 J

B an increase in efficiency of more than 15%

Deduce whether these claims are true.

Claim **A**

Claim **B**

(5)

(c) The first law of thermodynamics can be written as

$$Q = \Delta U + W$$

State the meaning of the terms Q and ΔU in this equation.

Q ____

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ΔU ____

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(2)

(d) For the air in process **5 → 1** in **Figure 2**, ΔU = –374 J

Calculate the energy that must be removed by cooling for process **5 → 1**.

energy removed by cooling = ____________________ J

(2)

(e) 0.060 mol of air is taken through the cycle.

Determine the maximum temperature in the cycle.

maximum temperature = ____________________ K

(3)

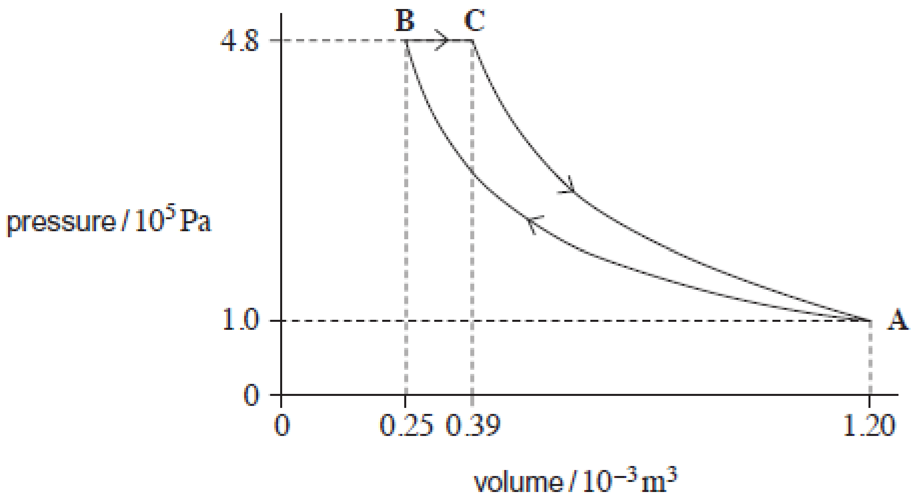
(Total 13 marks)

2. The figure below shows a theoretical engine cycle in which a fixed mass of ideal gas is taken through the following processes in turn:

A → B: isothermal compression from volume 1.20×10^{-3} m^3 and pressure 1.0×10^5 Pa to a volume 0.25×10^{-3} m^3 and maximum pressure of 4.8×10^5 Pa.

B → C: expansion at constant pressure with heat addition of 235 J.

C → A: adiabatic expansion to the initial pressure and volume at **A**.



(a) (i) Show that process **A → B** is isothermal.

(2)

(ii) Calculate the work done by the gas in process **B → C**.

work done ____________________ J

(1)

(b) Complete the table. Apply the first law of thermodynamics to determine values of Q, W and ΔU for each process and for the whole cycle. Use a consistent sign convention.

	Q / J	W / J	ΔU / J
process A → B		–188	
process B → C	+235		
process C → A		+168	
whole cycle		+47	0

(3)

(c) The overall efficiency of an engine is defined as

$$\frac{\text{net work output in one cycle}}{\text{energy supplied by heating from an external source in one cycle}}$$

Calculate the overall efficiency of the cycle.

overall efficiency ____________________

(1)

(d) Describe **two** problems that would be encountered in trying to design a real engine based on this cycle.

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(2)

(Total 9 marks)

3. (a) The first law of thermodynamics can be written $\Delta Q = \Delta U + \Delta W$.

(i) State the meaning of each term in this equation.

ΔQ ____

ΔU ____

ΔW ____

(ii) Explain why, for an isothermal expansion, the first law can be written $\Delta W = \Delta Q$.

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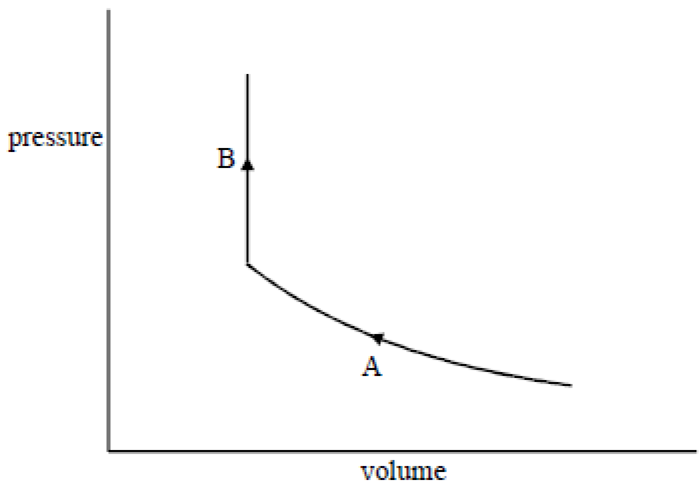
(5)

(b)



The diagram shows part of an ideal heat engine cycle in which a fixed mass of gas is taken through the following processes:

process A: isothermal compression at low temperature with an input of work of 83 J

process B: constant volume increase in pressure with an energy input by heating of 200 J

process C: isothermal expansion at high temperature with work output of 139 J

process D: constant volume cooling to the original pressure, volume and temperature

In this cycle, the energy input in process B is the same as the energy rejected in process D.

(i) On the diagram, draw in processes C and D to complete the whole cycle.

(ii) Complete the table by applying the first law of thermodynamics to each process and to the whole cycle.

process	ΔQ / J	ΔU / J	ΔW / J
A		0	–83
B	+200	+200	
C			+139
D			0
whole cycle			

(iii) The highest and lowest temperatures of the air during the cycle are 500K and 300K. Show that the thermal efficiency of the ideal cycle is equal to the maximum possible efficiency for any heat engine working between these temperature limits.

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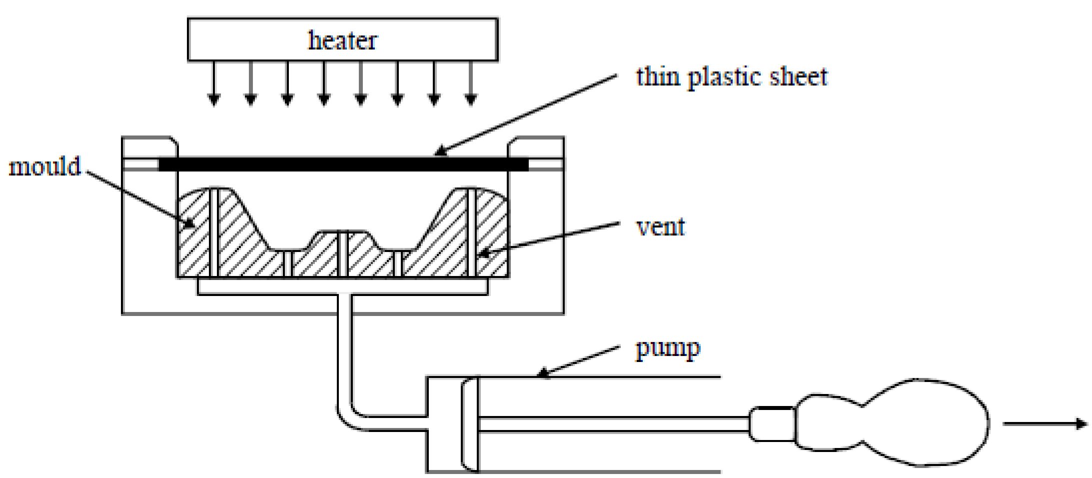
(9)

(Total 14 marks)

4. The diagram shows a section through a simple vacuum-forming machine for shaping a thin sheet of a thermoplastic material. The material is first softened by radiant heat from a heater mounted above it, and then forced into the cavity below, where it takes the shape of a wooden mould.

The force is applied by pulling back the pump handle quickly, causing a rapid expansion of the enclosed air which results in a sharp drop in pressure. The force arises from the difference in pressure between the atmosphere and the air in the cavity.



(a) To avoid the possibility of blistering the plastic sheet, the heater is left at low power until the plastic is soft enough to form. After the forming operation, the plastic is found to have developed cracks in its lower surface, which suggests that this surface was cooled during the operation.

Use the first law of thermodynamics, in the form $\Delta Q = \Delta U + \Delta W$, to explain why the rapid expansion of the air should cause it to cool.

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(3)

(b) The air in the cavity is initially at a pressure of 100 kPa and a temperature of 313K. When the pump is operated it expands adiabatically to 1.7 times its original volume before the plastic begins to move.

γ for air = 1.4

(i) Calculate the pressure of the air in the cavity just before the sheet begins to move.

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(ii) Calculate the temperature of the air at this stage.

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(5)

(c) State, with reasons, whether the air pressure in the cavity at the end of the pumping stroke would be higher or lower than that calculated in part (b) if the pump were operated slowly. Further calculation is not required, but a p–V sketch graph may be helpful.

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(2)

(Total 10 marks)