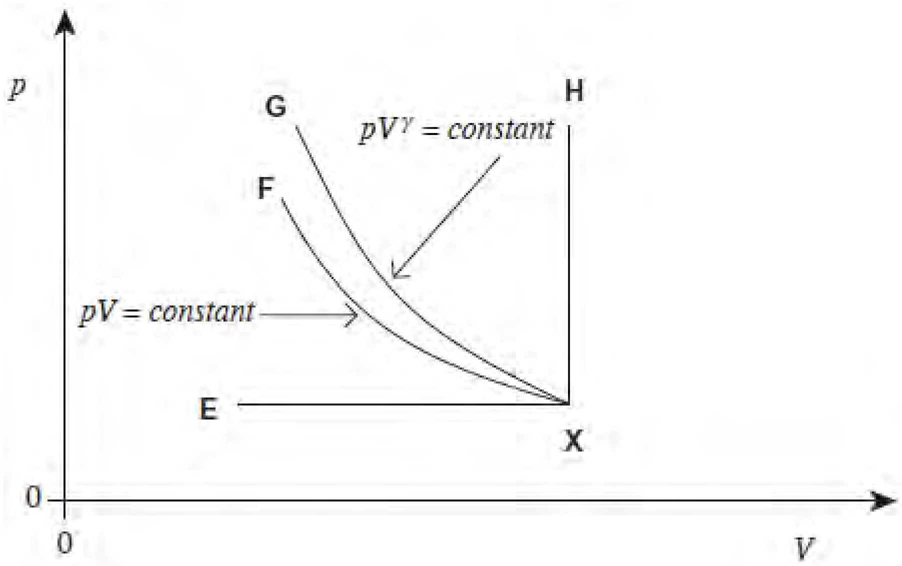
Q1.(a) A fixed mass of gas undergoes a change from one of states **E**, **F**, **G**, **H** to state **X** as shown on the pressure−volume ($p-V$) diagram in **Figure 1**.

Figure 1



Which change gives an increase in internal energy of the gas?
Tick (✓) the correct answer.

E to **X**	
F to **X**	
G to **X**	
H to **X**	

(1)

(b) **Figure 2** shows a cross−section through the cylinder of a compressor used to supply air at high pressure to an air tank. The air tank is not shown. The high−pressure air in the tank is used to release and apply the brakes on a lorry.

On the outward stroke of the piston, air is drawn into the cylinder at atmospheric pressure through the inlet valve. The outlet valve remains closed. On the inward stroke, the inlet valve closes and the increasing pressure in the cylinder causes the outlet valve to open, forcing air into the tank. A small clearance volume exists when the piston is at the end of its inward stroke. The crankshaft of the pump is driven by the lorry engine by a gear wheel which acts as a flywheel.

Air is pumped into the air tank until the pressure reaches 8.0×10^5 Pa.

Figure 3 shows the idealised $p-V$ diagram for one cycle in the initial stages of pumping, when the pressure in the air tank has reached approximately 4.5×10^5 Pa. The compressed air in the clearance volume at **C** must expand to point **D** before the inlet valve will open.

(i) The temperature of the air in the cylinder at the start of compression (point **A** on **Figure 3**) is 310 K.
Determine the temperature of the air at the point when the outlet valve is about to open. This is at point **B** on **Figure 3**.

temperature .... K

(2)

(ii) Determine the net work done **on** the air during the cycle shown in **Figure 3**.

work done .... J

(3)

Figure 2

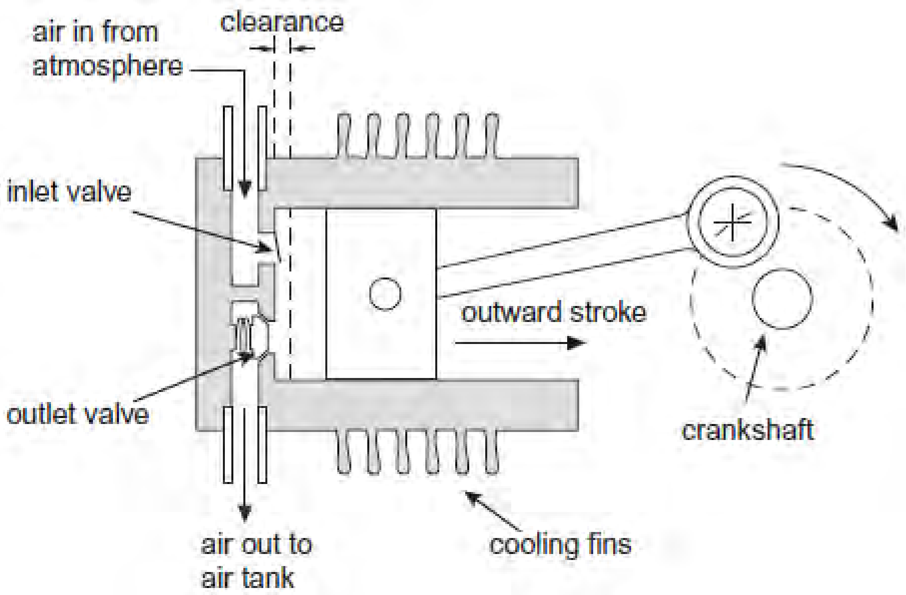
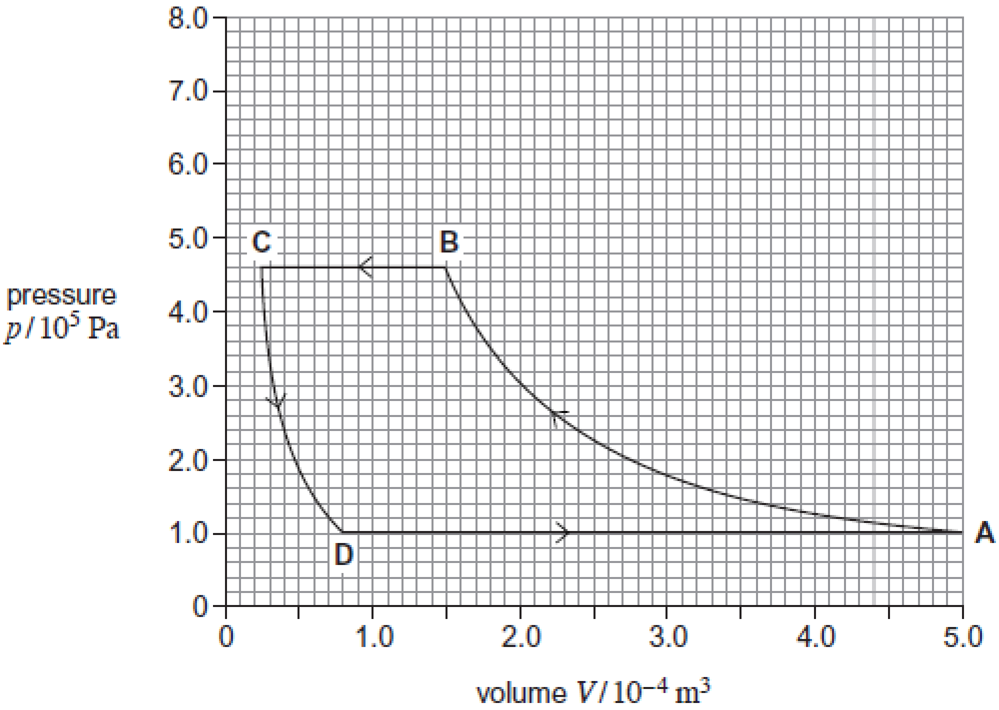


Figure 3



(iii) Determine the power input to the compressor when it runs at 420 revolutions per minute.

power .... W

(1)

(iv) Explain how the performance of the air compressor changes as the pressure in the tank **increases**. Calculations are not expected.

In your answer you should consider:

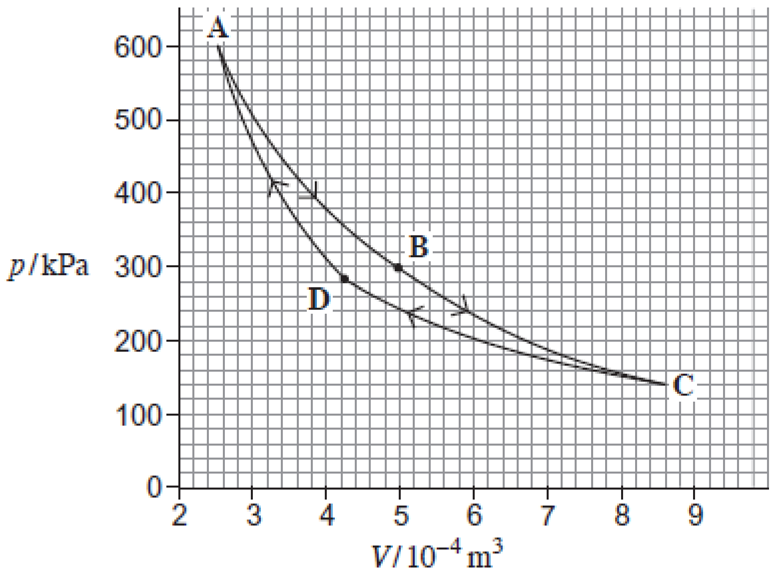
- how and why the $p-V$ diagram will change as the pressure in the tank increases
- how the temperature of the air in the cylinder changes
- the power input to the compressor, assuming it runs at constant speed
- the part played by the flywheel on the crankshaft.

The quality of your written communication will be assessed in your answer.

(6)
(Total 13 marks)

Q2. The Carnot cycle is the most efficient theoretical cycle of changes for a fixed mass of gas in a heat engine.

The graph below shows the pressure−volume ($p-V$) diagram for a gas undergoing a Carnot cycle of changes **ABCDA**.



(a) (i) Show that during the change **AB** the gas undergoes an isothermal change.

(3)

(ii) Explain how the first law of thermodynamics applies to the gas in the change **BC**.

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....

....

(3)

(iii) Determine the ratio $\frac{T_A}{T_C}$,

where T_A is the temperature of the gas at **A** and T_C is the temperature of the gas at **C**.

ratio ....

(3)

(b) Show that the work done during the change **AB** is about 110 J.

(2)

(c) When running at a constant temperature, one practical engine goes through 2400 cycles every minute. In one complete cycle of this engine, 114 J of energy has to be removed by a coolant so that the engine runs at a constant temperature. The temperature of the coolant rises by 18 °C as it passes through the engine.

Calculate the volume of the coolant that flows through the engine in one second.

specific heat capacity of coolant = 3.8×10^3 J kg^{-1} K^{-1}
density of coolant = 1.1×10^3 kg m^{-3}

volume flowing in one second .... m^3

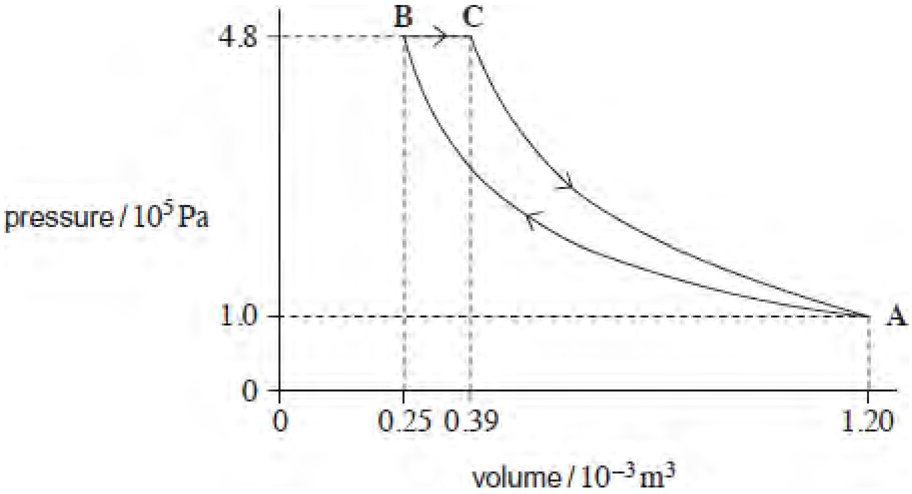
(3)
(Total 14 marks)

Q3. 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**	**Δ*U* / 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)