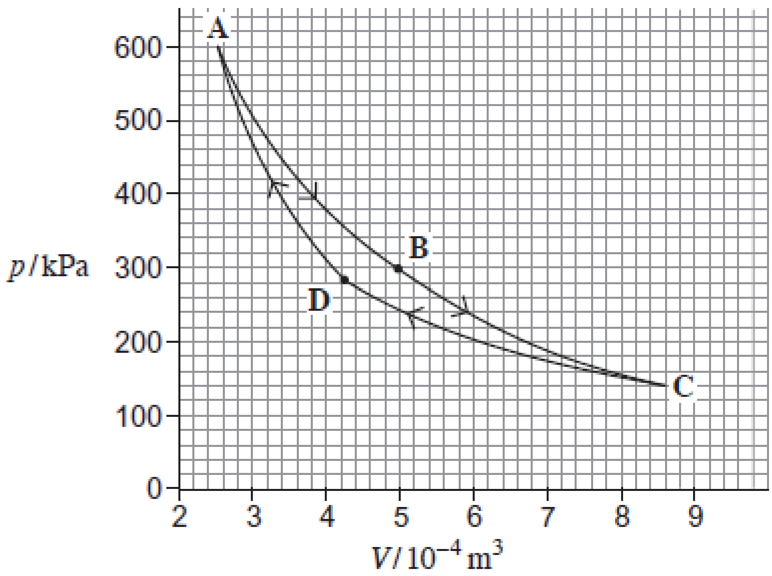
Q1. The Carnot cycle is the most efficient theoretical cycle of changes for a fixed mass of gas in a heat engine.

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.

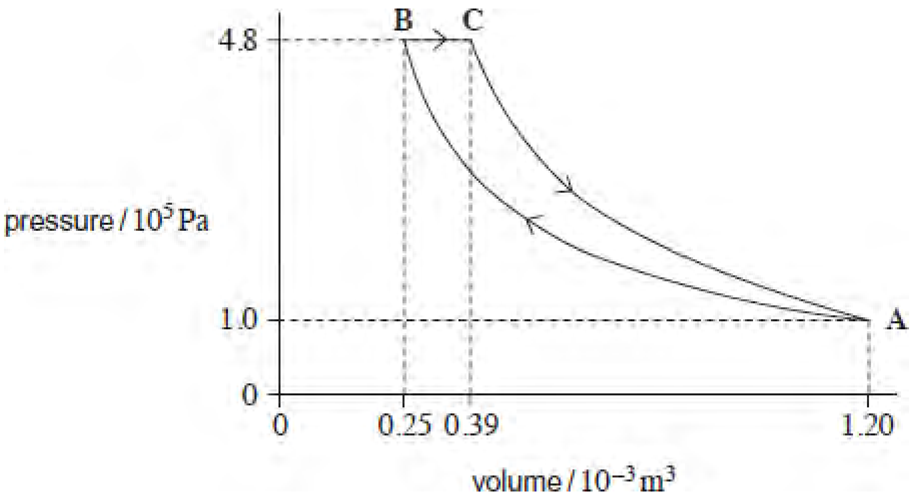
specific heat capacity of coolant = 3.8×10^3 J kg^{-1} K^{-1}
density of coolant = 1.1×10^3 kg m^{-3}

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

(3)
(Total 14 marks)

Q2. 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 $\mathbf{B} \rightarrow \mathbf{C}$.

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 $\mathbf{A} \rightarrow \mathbf{B}$		–188	
process $\mathbf{B} \rightarrow \mathbf{C}$	+235		
process $\mathbf{C} \rightarrow \mathbf{A}$		+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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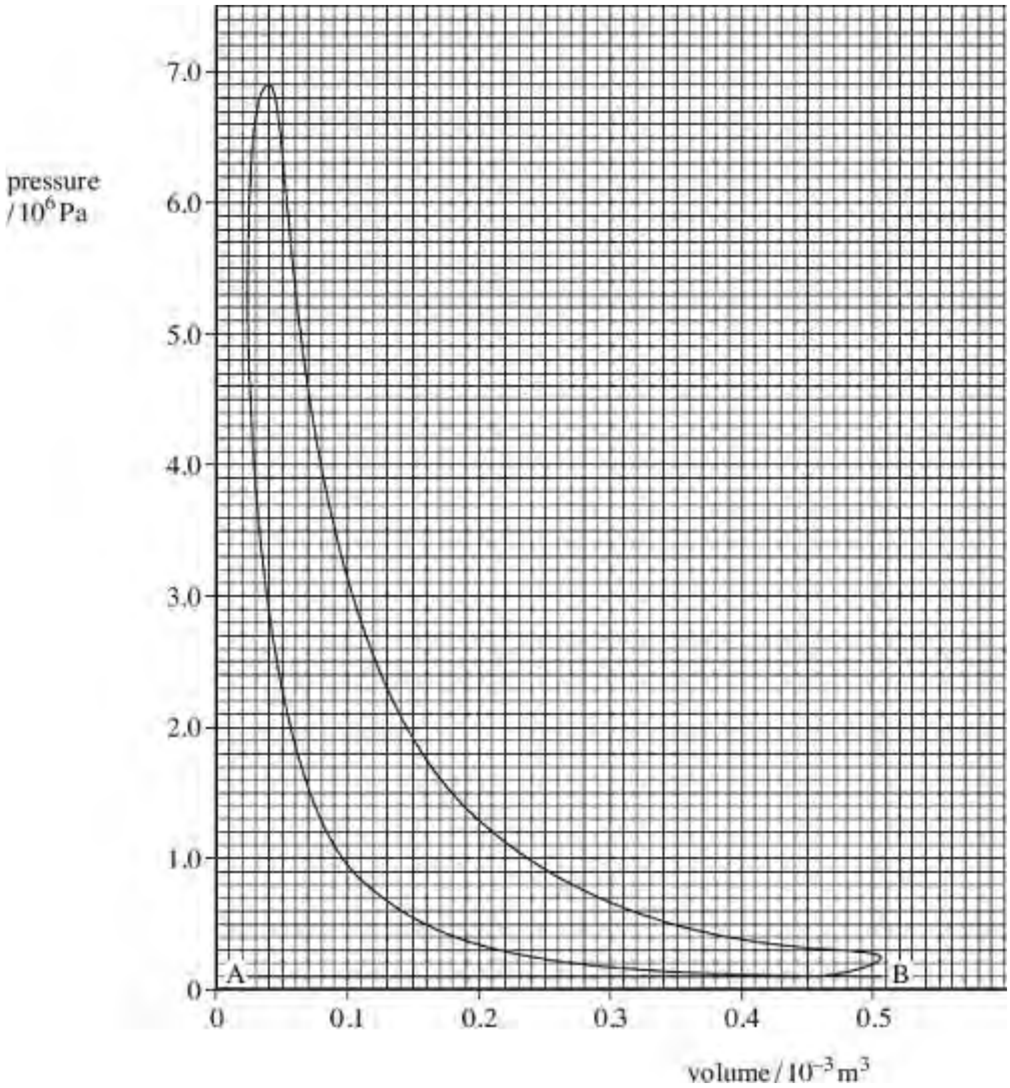
(2)

(Total 9 marks)

Q3. A four-stroke diesel engine with four cylinders is running at constant speed on a test bed. An indicator diagram for **one cylinder** is shown in the figure below and other test data are given below:

measured output power of engine (brake power) = 55.0 kW
fuel used in 100 seconds = 0.376 litre
calorific value of fuel = 38.6 MJ litre^{-1}
engine speed = 4100 rev min^{-1}



(a) (i) Determine the indicated power of the engine, assuming all cylinders give the same power.

answer = ... kW

(4)

(ii) Calculate the overall efficiency of the engine.

answer = ...

(3)

(b) Account for the difference between the indicated power and brake power.

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(1)

(c) What is represented by the line AB on the figure above?

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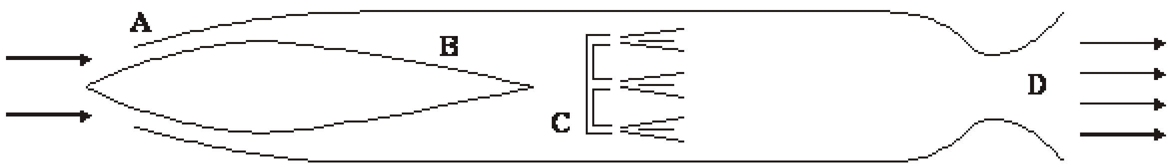
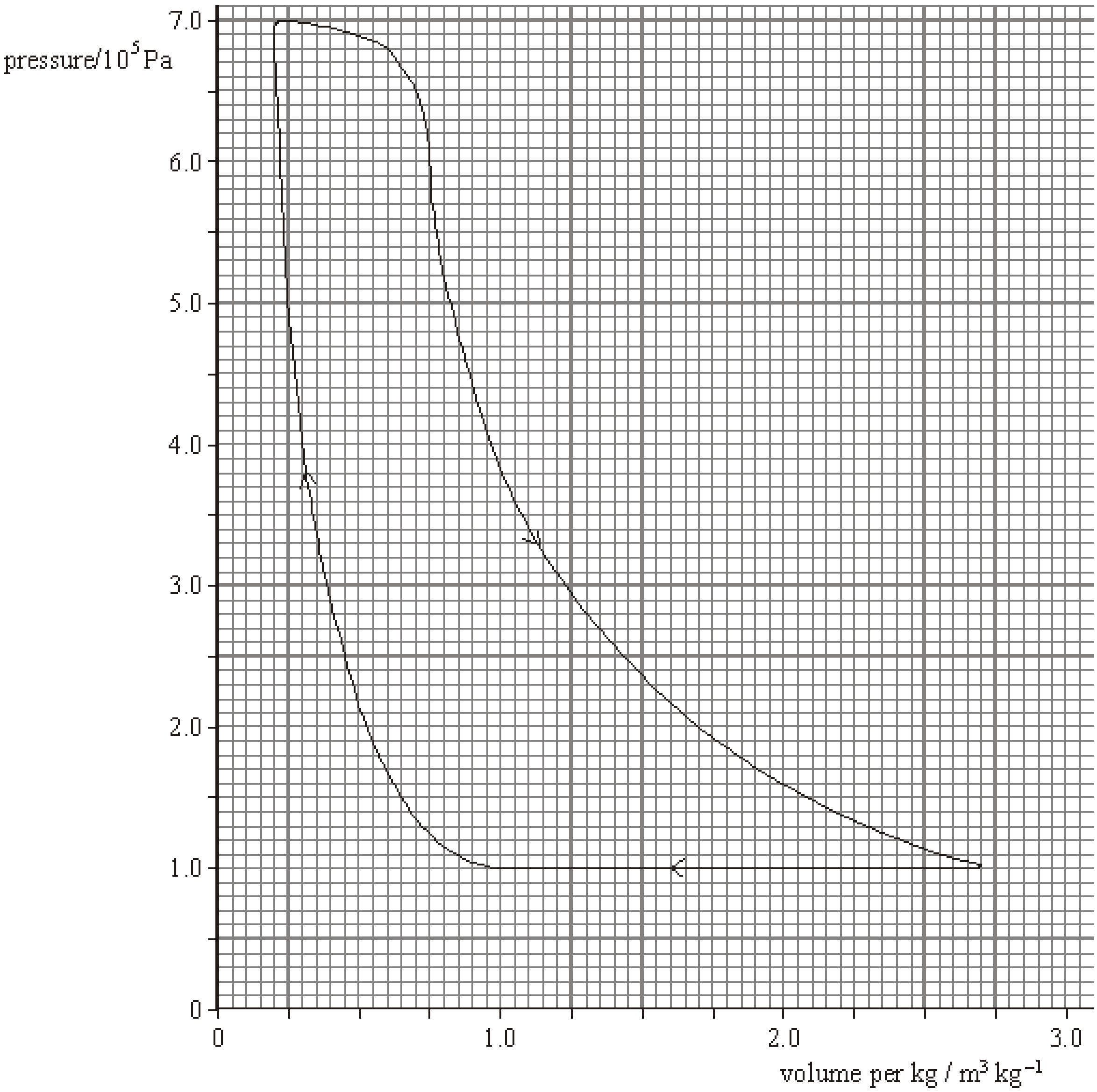
(1)
(Total 9 marks)

Q4. The ram jet engine was used as a cheap and efficient propulsion unit for high speed guided missiles. The figure below shows a section through this engine.



When moving at high speed, air enters the nose at **A** and its pressure increases up to region **B**. At **C**, fuel is injected directly into the air stream where it is ignited, and the burning gases are exhausted at high speed through the nozzle at **D**. This provides the thrust.

The graph shows the pressure-volume diagram for 1.0 kg of air passing through the engine. Note that the volume axis has units of $m^3\ kg^{-1}$ i.e. the volume for every kg of air that passes through the engine.



(a) (i) Use the graph to show that the work done for every kg of air that passes through the engine is about 500 kJ.

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(ii) The mass flow rate of the air through the engine is 9.9 kg s^{-1}. Determine the work done in one second in the engine. This is the equivalent of the indicated power of the engine.

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(iii) Because of the high speed of the air in the engine, there is significant frictional heating amounting to a power loss of 430 kW. Determine the power output of the engine (available for thrust).

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(5)

(b) The engine consumes fuel at the rate of 0.30 kg per second. The calorific value of the fuel is 44 MJ kg^{-1}. Calculate

(i) the input power to the engine,

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(ii) the overall efficiency of the engine.

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(2)
(Total 7 marks)

Q5. Test-bed measurements made on a single-cylinder 4-stroke petrol engine produced the following data:

mean temperature of gases in cylinder during combustion stroke	820 °C
mean temperature of exhaust gases	77 °C
area enclosed by indicator diagram loop	380 J
rotational speed of output shaft	1800 rev min^{-1}
power developed by engine at output shaft	4.7 kW
calorific value of fuel	45 MJ kg^{-1}
flow rate of fuel	2.1×10^{-2} kg min^{-1}

(a) Estimate the maximum theoretical efficiency of this engine.

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(2)

(b) Calculate the indicated power of the engine.

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(2)

(c) Calculate the power dissipated in overcoming the frictional losses in the engine.

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(1)

(d) Calculate the rate at which energy is supplied to the engine.

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(1)

(e) Calculate the overall efficiency of the engine.

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(1)
(Total 7 marks)