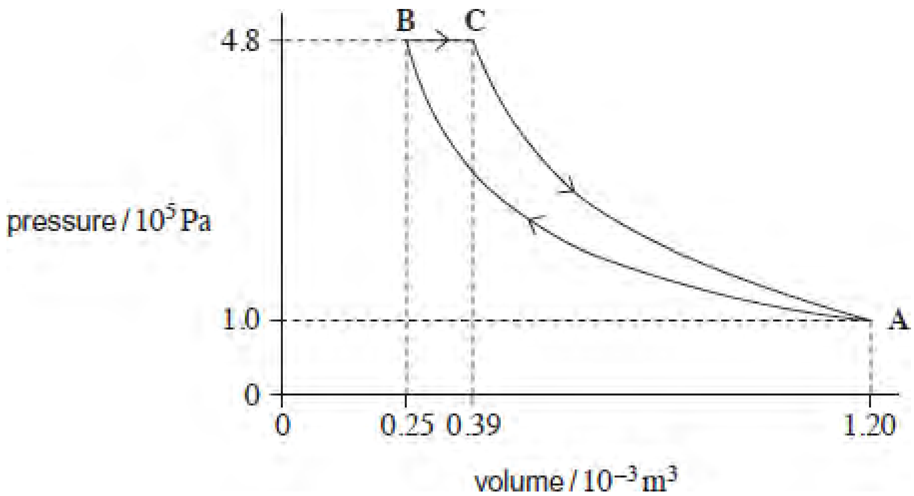
Q1. The figure below shows a theoretical engine cycle in which a fixed mass of ideal gas is taken through the following processes in turn:

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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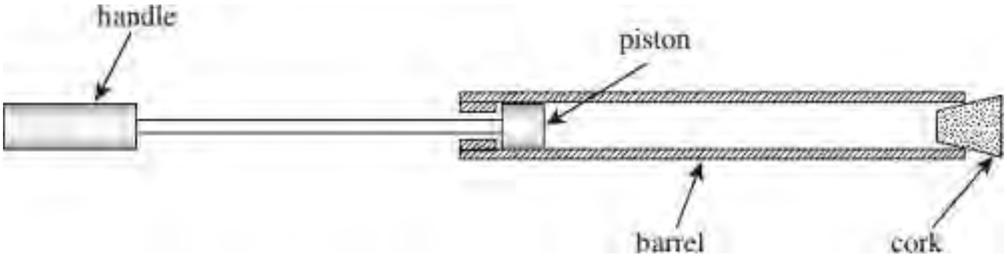
(2)
(Total 9 marks)

Q2. The figure below shows a child's 'pop' gun in which a piston is pushed quickly along the barrel, compressing the air in the barrel. When the pressure is high enough, the cork is expelled at high speed from the end of the barrel.



The figure above shows the gun before it is 'fired'. The air in the barrel is at a pressure of 1.0×10^5 Pa, a temperature of 290 K and the volume is 2.1×10^{-5} m^3.

(a) (i) The volume of air in the barrel at the instant the cork is expelled is 1.2×10^{-5} m^3.
Calculate the pressure of the air in the barrel at the instant the cork is expelled.
Assume that the air is compressed adiabatically.
adiabatic index, γ, for air = 1.4

answer = ... Pa

(2)

(ii) Calculate the maximum temperature reached by the air in the gun. Give your answer to an appropriate number of significant figures.

answer = ... K

(3)

(b) The work needed to compress the air adiabatically from 2.1×10^{-5} m^3 to 1.2×10^{-5} m^3 is 1.4 J. Use the first law of thermodynamics to determine the change in internal energy of the air during the compression. Explain how you arrived at your answer.

answer = ... J

(2)

(c) Explain, giving your reasons, whether the volume of air in the barrel at the point when the cork leaves the gun would be less than, equal to, or greater than 1.2×10^{-5} m^3 if the handle of the gun had been pushed in slowly. Assume there is no leakage of air past the cork or piston. You may find it helpful to sketch a *p* - *V* diagram of the compression.

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(3)
(Total 10 marks)

Q3. In an ideal 'hot air' engine, a fixed mass of air is continuously taken through the following four processes:

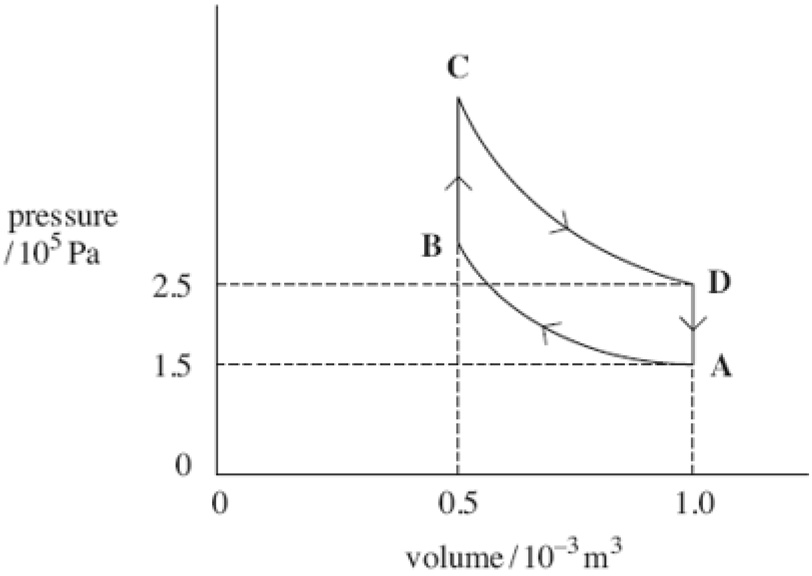
A → B isothermal compression at a temperature of 300 K. The work done on the air is 104 J.

B → C heating at constant volume.

C → D isothermal expansion. The work done by the expanding air is 173 J.

D → A cooling at constant volume.

The cycle is shown in the figure below.



(a) (i) Show that the temperature of the air at point D is 500 K.

(2)

(ii) Apply the first law of thermodynamics to calculate the energy supplied by heat transfer in process C → D.

answer = ... J

(2)

(b) The engine contains a device called a regenerator which stores **all** the energy rejected by cooling in process D → A and gives up **all** this energy to the air again in process B → C. This means that energy must be supplied to the air by heat transfer from an external source **only** in process C → D.

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

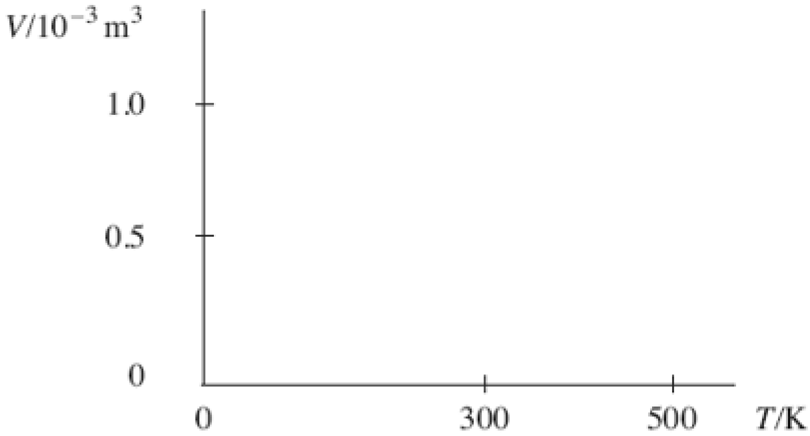
answer = ... J

(1)

(ii) Show that the efficiency of the cycle is the same as the maximum possible efficiency of any heat engine operating between the same highest and lowest temperatures in the cycle.

(2)

(c) On the axes below, sketch the cycle on a graph of volume *V* against temperature *T*. Label the points A, B, C and D.



(2)

(d) Several inventors have tried to build an engine that works on this cycle. Give **two** reasons why they have been unsuccessful.

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(2)
(Total 11 marks)

Q4.(a) The first law of thermodynamics can be written $\Delta Q = \Delta U + \Delta W$

State the usual meaning of each term in the equation.

ΔQ ....

ΔU ....

ΔW ....

(3)

(b) A fixed mass of gas in a cylinder is heated in two stages:

stage 1 at constant volume, when 10.0 kJ of heat is supplied,
stage 2 when it expands isothermally and does 6.0 kJ of work.

Apply the first law of thermodynamics to each of these processes and complete the table to show, for each process, the values of ΔQ, ΔU and ΔW.

	ΔQ	ΔU	ΔW
stage 1 constant volume	+10.0 kJ		
stage 2 isothermal			+6.0 kJ

(4)
(Total 7 marks)