Q1.

The Lenoir engine was the first successful internal combustion engine.

Figure 1 shows the basic form of the Lenoir engine. The piston rod drives a crankshaft which is not shown. The fuel is a mixture of gas and air.

Figure 1

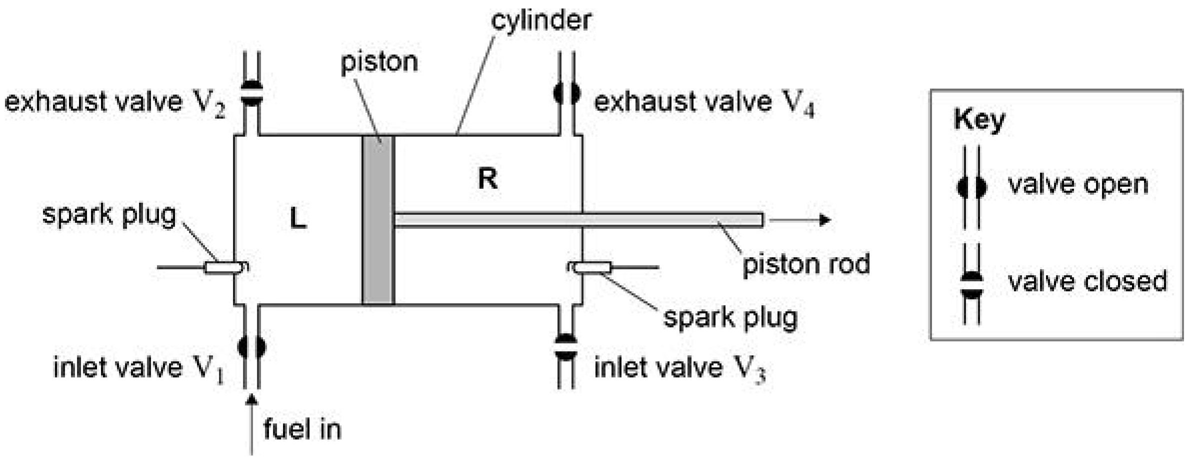
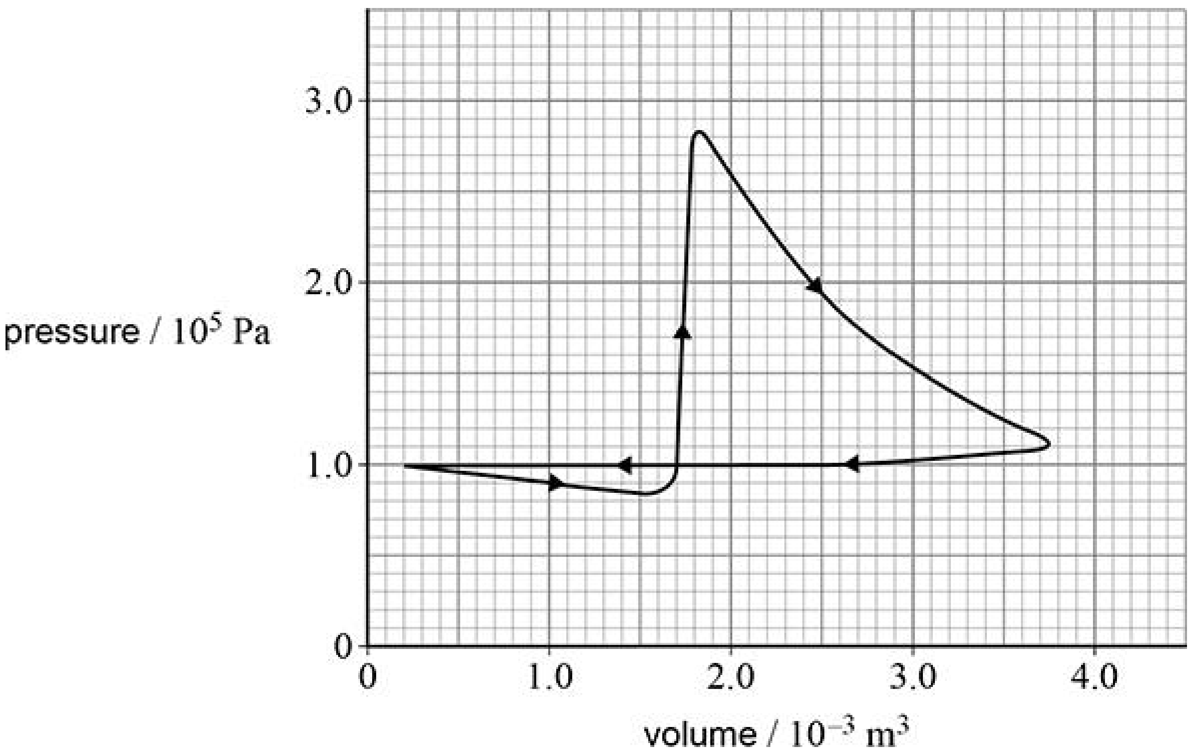


Figure 2 shows an indicator diagram for the space **L**, taken during a test on a Lenoir engine.

Figure 2



In one cycle the following changes occur in **L**.

- **Induction**. The piston starts at the left-hand end of the cylinder. It moves to the right and fuel passes through the open inlet valve V_1 into **L**. **Figure 1** shows the piston during this induction process, with V_1 open.
- **Ignition**. When the piston is nearly halfway along the cylinder, V_1 is closed. A spark ignites the fuel causing a sudden rise in pressure.
- **Expansion**. The hot gases expand and the piston moves to the end of the stroke.
- **Exhaust**. The exhaust valve V_2 opens. The piston moves to the left. The exhaust gases are expelled at atmospheric pressure.

The same processes are repeated in space **R** one half of a revolution of the crankshaft later than in **L**. So when the piston is moving to the left, induction, ignition and expansion occur in **R** at the same time as the exhaust process occurs in **L**.

(a) The indicator diagram is for a rotational speed of the crankshaft of 120 rev min^{-1}.

Determine, using **Figure 2**, the indicated power of the engine.
Assume that the indicator diagram for **R** is identical to the indicator diagram for **L**.

indicated power = ____________________ W

(5)

(b) The following data are taken during the test on the engine:

fuel consumption = 6.44×10^{-4} m^3 s^{-1}
calorific value of fuel = 18.0×10^{6} J m^{-3}
torque at crankshaft = 39.0 N m
rotational speed = 120 rev min^{-1}

Calculate the input power and the output (brake) power of the engine.

input power = ____________________ W

output power = ____________________ W

(2)

(c) The output power of a four-stroke petrol engine of a similar working volume to that of the Lenoir engine is about 150 kW.

Suggest **two** reasons for the very low output power of the Lenoir engine compared with a four-stroke petrol engine.

1 ____

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2 ____

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(2)

(d) Which statement is correct?

Tick (✓) **one** box.

Thermal efficiency is a measure of how much of the indicated power is converted into output power.	☐
Overall efficiency is the product of mechanical efficiency and thermal efficiency.	☐
Mechanical efficiency is equal to friction power divided by indicated power.	☐
Input power is equal to indicated power plus friction power.	☐

(1)

(Total 10 marks)

Q2.

(a) The first law of thermodynamics can be expressed by the equation $Q = \Delta U + W$.

State the meaning of each term in this equation.

Q ____

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ΔU ____

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W ____

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(2)

(b) A system consists of a perfectly insulated room containing only an empty refrigerator.
The refrigerator is connected to the mains electricity and the refrigerator door is open.

Deduce, by applying the first law of thermodynamics, whether the internal energy of the room increases, decreases or stays the same.

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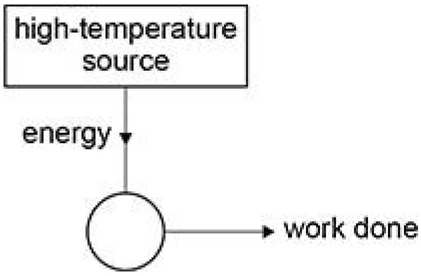
(3)

One definition of an ideal heat engine is:

'a device which provides the maximum possible output of work from a given input of energy by heat transfer.'

The figure below shows a heat engine that appears to agree with this definition. The engine takes in energy from a high-temperature source and work is done by the engine.



(c) Complete above figure so that the engine obeys the second law of thermodynamics.

(1)

(d) Explain why the maximum theoretical efficiency of an ideal heat engine must be less than 100%.

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(2)
(Total 8 marks)

Q3.

(a) The first law of thermodynamics can be written as:

$$Q = \Delta U + W$$

State what Q represents in this equation.

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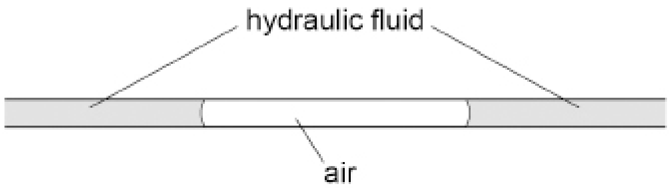
(1)

Air in the brake pipe of a bicycle hydraulic brake system can be dangerous.
The figure below shows a bubble of air in a brake pipe.



Assume that the hydraulic fluid is incompressible.
During a sudden application of the brake, the air is compressed adiabatically to a high pressure.

(b) The work done on the air when it is compressed is 10.8 mJ.

Which row is correct for this adiabatic compression?

Tick ✓ **one** box.

W / mJ	Q / mJ	ΔU / mJ	
−10.8	0	10.8	☐
10.8	10.8	0	☐
−10.8	−10.8	0	☐
10.8	0	−10.8	☐

(1)

(c) The initial conditions for the air are:

volume of air = 2.91×10^{-8} m^3

pressure of air = 1.05×10^5 Pa

temperature of air = 293 K.

During sudden braking, the air in the bubble is compressed adiabatically to a volume of 3.19×10^{-9} m^3.

Calculate the pressure and the temperature of the air immediately after the compression.

γ for air = 1.4

pressure = ____________________ Pa

temperature = ____________________ K

(3)

(d) To produce the adiabatic change, the brake lever is pulled very quickly. The cyclist thinks that by applying the brake slowly, the work done to compress the bubble to a volume of 3.19×10^{-9} m^3 will be greater than 10.8 mJ.

Deduce without calculation whether the cyclist is correct.

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(2)

(Total 7 marks)

Q4.

Figure 1 shows the p–V diagram for a theoretical diesel engine cycle.
Figure 2 shows the indicator diagram for a real four-stroke diesel engine working between the same maximum and minimum volumes.

Figure 1

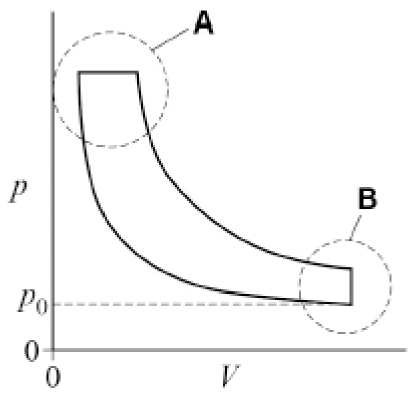
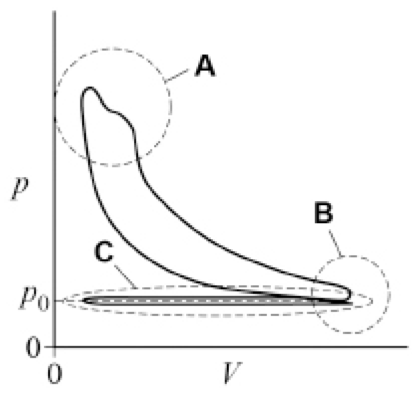


Figure 2



p_0 is atmospheric pressure.

Compare the indicator diagram with the theoretical diesel cycle.
In your answer, explain:

- the differences between region **A** on **Figure 1** and region **A** on **Figure 2**
- the differences between region **B** on **Figure 1** and region **B** on **Figure 2**
- why the features shown in region **C** appear only on the indicator diagram
- why the efficiency of the real engine will always be less than the efficiency predicted by an analysis of the theoretical cycle.

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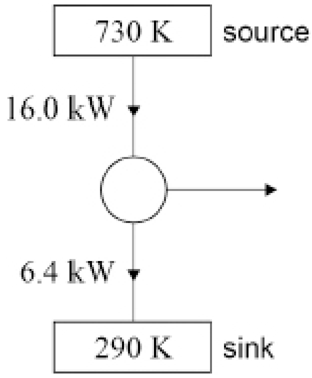
(Total 6 marks)

Q5.

Figure 1 shows an ideal heat engine.

Figure 1



The engine operates between a source at a temperature of 730 K and a sink at a temperature of 290 K.
The input power is 16.0 kW and the power rejected to the sink is 6.4 kW.

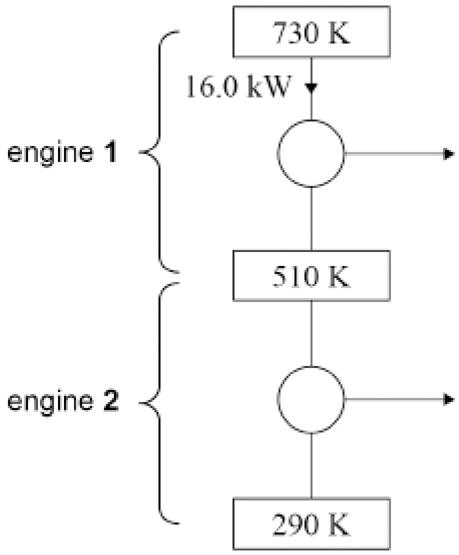
(a) Calculate the efficiency of this engine.

efficiency = ____________________

(1)

(b) **Figure 2** shows another system operating between the same overall temperatures and with the same input power as the engine in **Figure 1**. This system consists of two ideal engines.

Figure 2



The sink for engine **1** forms the source for engine **2**. The temperature of the intermediate reservoir is 510 K.
All the energy rejected by heat transfer in engine **1** provides the input energy to engine **2**.
A student suggests that the system in **Figure 2** can provide more output power and be more efficient than the engine in **Figure 1**.

Deduce whether the student's suggestions are correct.
You may annotate **Figures 1** and **2**.

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(3)

(Total 4 marks)

Q6.

(a) Explain what is meant by an adiabatic change.

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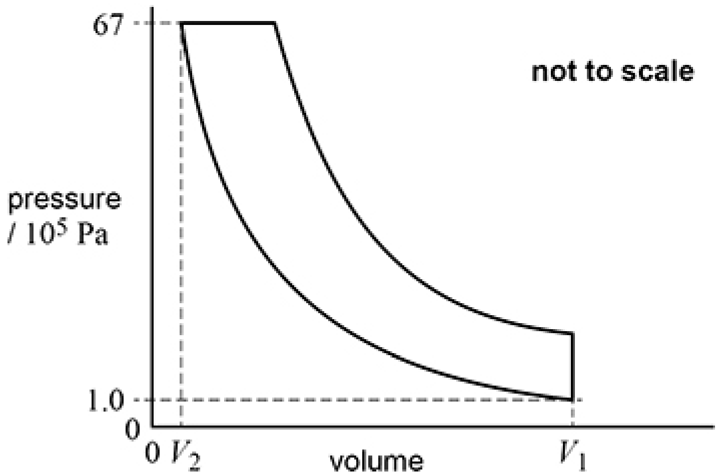
(1)

(b) **Figure 1** shows the p–V diagram for an ideal diesel engine cycle.

Figure 1



In this cycle, air is compressed adiabatically from a pressure of 1.0×10^5 Pa and volume V_1 to a pressure of 67×10^5 Pa and volume V_2.
The adiabatic index γ for air = 1.4

Calculate the compression ratio $\frac{V_1}{V_2}$.

compression ratio = ____________________

(2)

(c) Explain why the compression ratio for a diesel engine must be greater than the compression ratio for a petrol engine.

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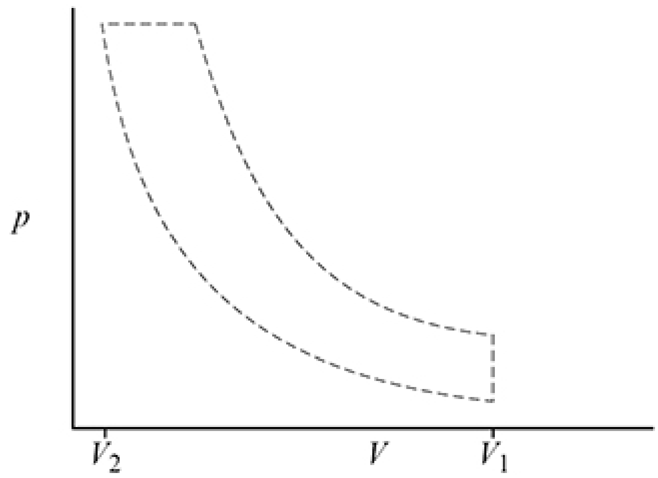
(2)

The dashed lines in **Figure 2** show the p–V diagram for the ideal diesel engine cycle.

(d) Draw, on **Figure 2**, a typical indicator diagram for a real four-stroke diesel engine with the same values of V_1 and V_2.

Figure 2



(2)

(e) Mark with an **X** on your diagram the point where the injection of fuel starts.

(1)

(f) Explain **two** differences between the ideal cycle and the indicator diagram for the real engine.

1. ____

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2. ____

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(2)

(Total 10 marks)

Q7.

Figure 1 shows a low-voltage solid-state thermoelectric cooling element.
The element is a square of side 40 mm and is 4 mm thick.

Figure 1

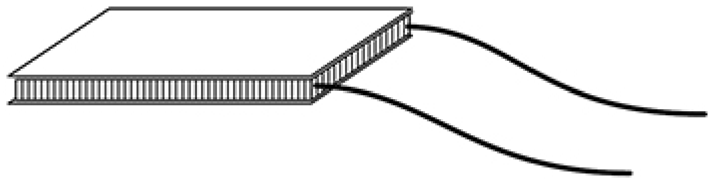
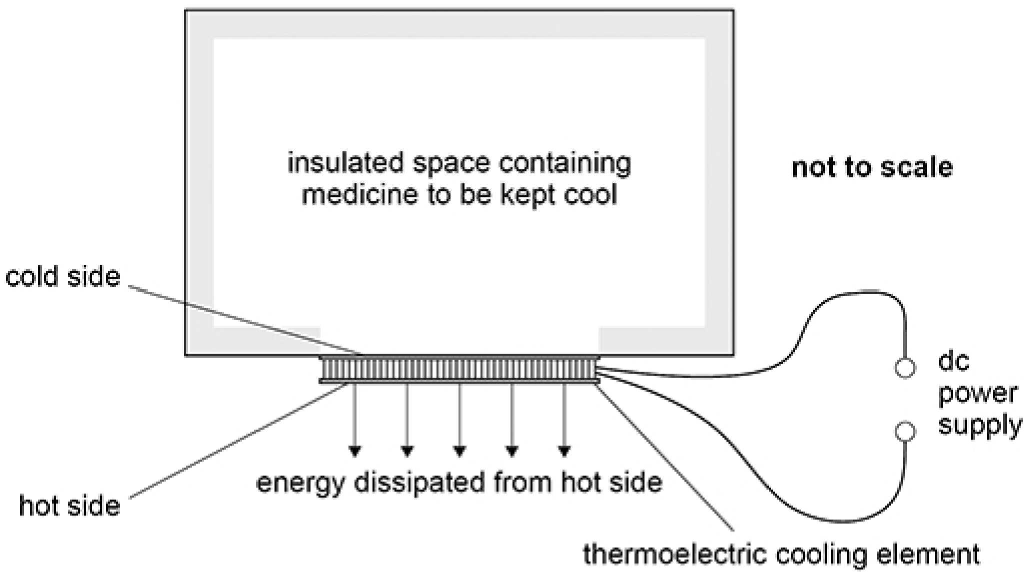


Figure 2 shows how the element is used as part of a thermoelectric refrigerator to keep small quantities of medicine at a low temperature.

Figure 2



The manufacturer's data for the element show that when the temperature of the hot side is 35 °C and the temperature of the cold side is 5 °C:

- the rate at which energy is dissipated from the hot side is 65 W
- the electrical power supplied is 28 W.

(a) It is claimed that the coefficient of performance (COP) of a thermoelectric refrigerator is much less than the COP of an ideal refrigerator.

Discuss whether the claim is valid for the thermoelectric refrigerator in this question.

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(4)

(b) Suggest why a small value of the COP might be acceptable for this particular application of a thermoelectric cooling element.

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(2)

(Total 6 marks)