AQA A-LEVEL PHYSICS · 7408

PHYSICS



EXAM QUESTION PACK

3.11.2 THERMODYNAMICS AND ENGINES

SCORE	PERCENTAGE
/106	%

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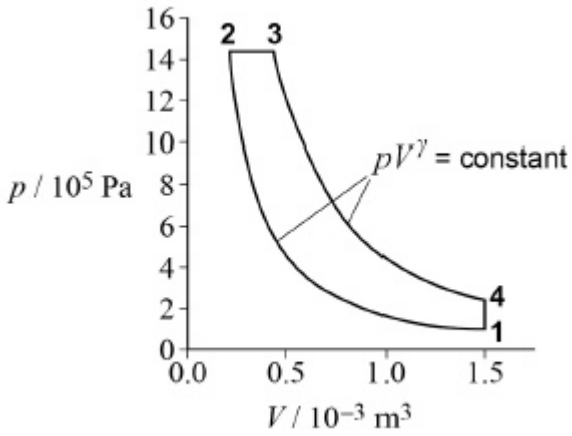
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Q1.

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. ☐

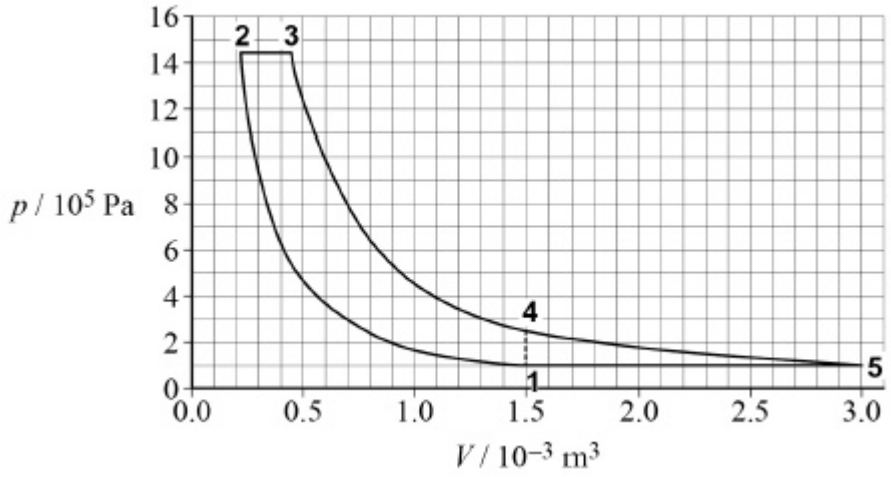
(1)

(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

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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

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)

Q2.

The National Grid is supplied mainly from power stations which have overall efficiencies of up to about 40%

The table shows the average power requirements of a large paper-manufacturing business (a paper mill).

Requirement	**Average power / MW**
for driving electric motors for wood grinders, pumps, fans, etc.	49
for heating, i.e. boiling and drying in the paper-making process and for heating the	141

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paper mill	
for running electrical office equipment, lighting, etc.	8

The paper mill can either

- take all of its energy from the National Grid, or
- install an electrical generator of output 60 MW driven by a gas turbine of efficiency 36% as part of a combined heat and power (CHP) scheme. The hot exhaust gases from the turbine are used to produce steam at high temperature and pressure for heating.

The owners of the paper mill are considering the CHP option.

Explain, with reference to the data above and any other factors, the advice you would give them.

In your answer you should

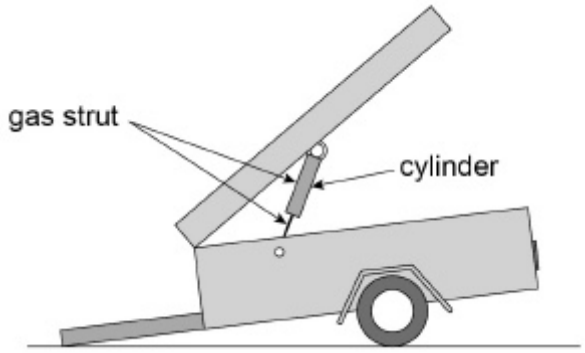
- explain why the maximum theoretical efficiency of a heat engine is much less than 100%
- use the information above, including the numerical data, to compare the two options.

(Total 6 marks)

Q3.

The diagram shows a gas strut supporting the lid of a trailer.

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A fixed mass of nitrogen gas is sealed into the cylinder of the strut.

(a) The gas is initially at a pressure of 1.2×10^6 Pa, a volume of 9.0×10^{-5} m^3 and a temperature of 290 K.

When the lid is closed quickly the gas is compressed rapidly to a final volume of 6.8×10^{-5} m^3.

Calculate the pressure and temperature of the gas at the end of the compression assuming the compression to be an adiabatic process.

adiabatic index γ for nitrogen = 1.4

pressure = _____ Pa

temperature = _____ K

(4)

(b) Explain why the rapid compression of the gas can be assumed to be an adiabatic process.

_____

_____

_____

_____

_____

(2)

(c) When the lid is closed slowly, the compression can be assumed to be isothermal.

The gas can be compressed either isothermally or adiabatically from the same initial conditions to the same final volume.

Compare without calculation the work done in each process.

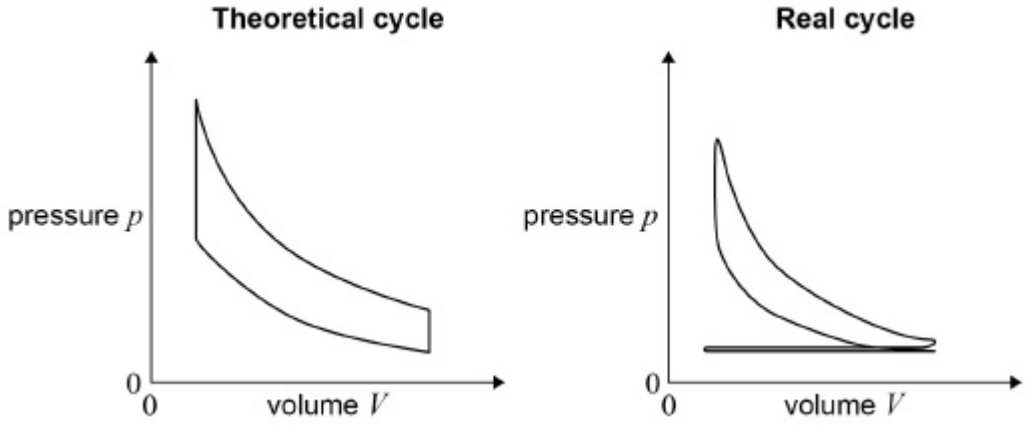
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(3)

(Total 9 marks)

Q4.

The diagram shows the p—V diagram for a theoretical petrol engine cycle compared to the indicator diagram for a real four-stroke petrol engine with the same maximum and minimum volumes.



Compare the theoretical and real engine cycles. In your answer you should:

- state and explain the differences between the cycles
- explain why the work output per cycle of the real engine is less than that predicted by an analysis of the theoretical cycle.

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_____

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_____

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(Total 6 marks)

Q5.

(a) An ideal heat pump and an ideal refrigerator operate between the same hot and cold spaces.

Which statement relating to the coefficient of performance (COP) is correct?
Tick (✓) the correct answer.

The COP of the refrigerator must be < 1.	☐
The COP of the heat pump must be greater than the COP of the refrigerator.	☐
The COP of the heat pump will increase if the temperature of the hot space is increased.	☐
The COP of the refrigerator will decrease if the cold space temperature increases.	☐

(4)

(b) An ideal refrigerator operates between a cold space at a temperature of –1 °C and a hot space at a temperature of 70 °C.

Calculate the input power to the refrigerator if the rate of transfer of energy to the hot space is 100 W.

input power = _____ W

(3)

(Total 4 marks)

Q6.

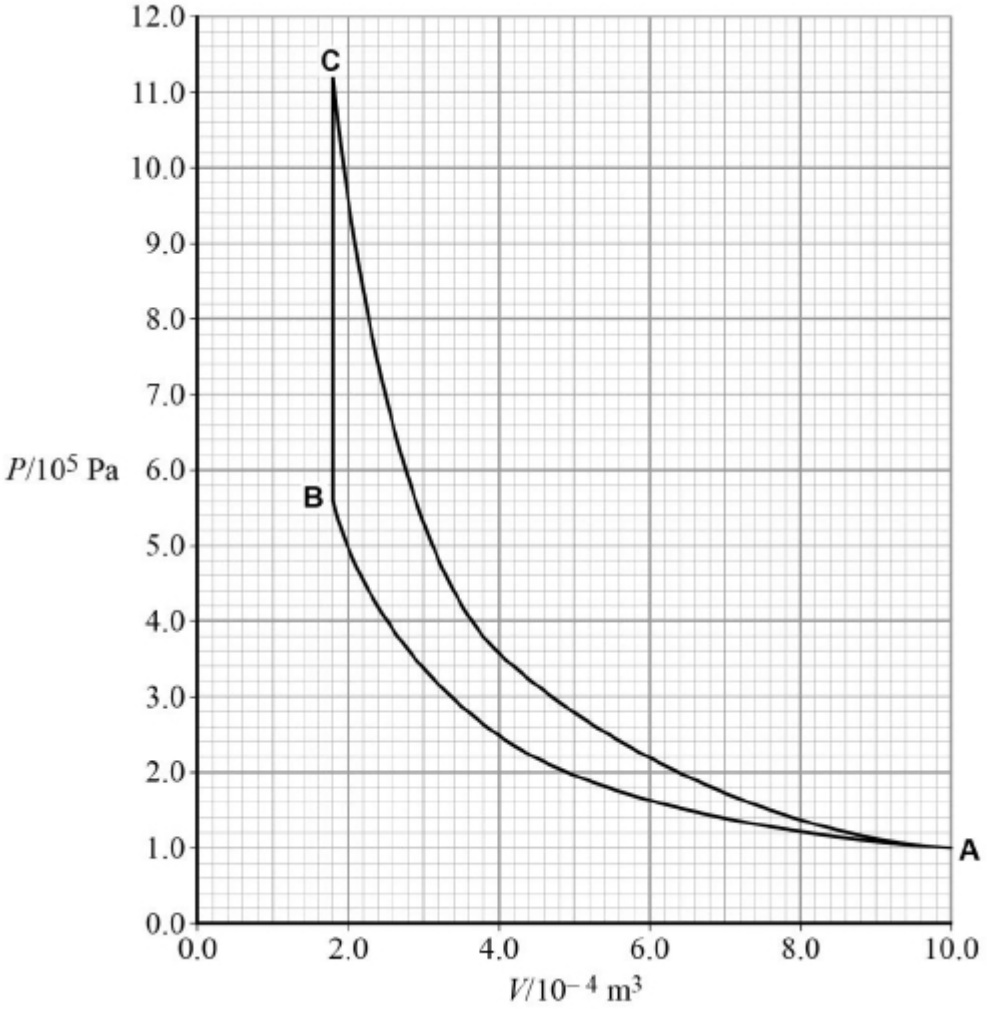
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The graph below shows a $p - V$ diagram of a theoretical engine cycle in which a fixed mass of gas at an initial pressure of 1.00 ×10^5 Pa and temperature 295 K is taken through the following stages in turn:

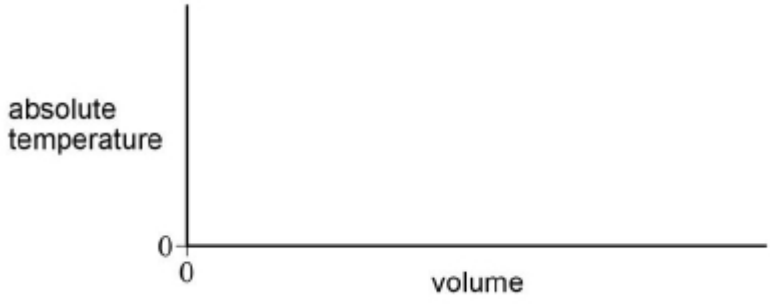
A ⟶ **B** isothermal compression

B ⟶ **C** heat addition of 251 J at constant volume to a temperature 2.0 times the initial temperature

C ⟶ **A** adiabatic expansion to the initial temperature and pressure.



(a) Sketch, on the axes below, a graph to show how the temperature will vary with volume during the cycle. Label the points **A**, **B** and **C**.



(2)

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(b) Determine the work output of the cycle.

work = _____ J

(3)

(c) Determine the power output of this theoretical engine if the engine were to run at 80 cycles per second.

power = _____ W

(1)

(d) An engineer is thinking about designing a real engine which works as closely as possible to this cycle.

Discuss some of the problems that will have to be overcome. Go on to discuss, with reference to the power output and efficiency of the cycle, whether the engineer should go ahead with the design.

_____

_____

_____

_____

_____

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_____

_____

(6)

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(Total 12 marks)

Q7.

(a) Explain what is meant by a reversed heat engine.

_____

_____

_____

_____

_____

(2)

(b) The coefficient of performance of a heat pump is given by

$$COP_{hp} = \frac{Q_H}{Q_H - Q_C}$$

Explain the term Q_H with reference to a heat pump used to provide heating in a building.

_____

_____

_____

(1)

(c) An ideal heat engine of efficiency 0.50 is reversed to operate as a heat pump working between the same temperature limits.
Determine the coefficient of performance of the heat pump.

COP_{hp} _____

(2)

(Total 5 marks)

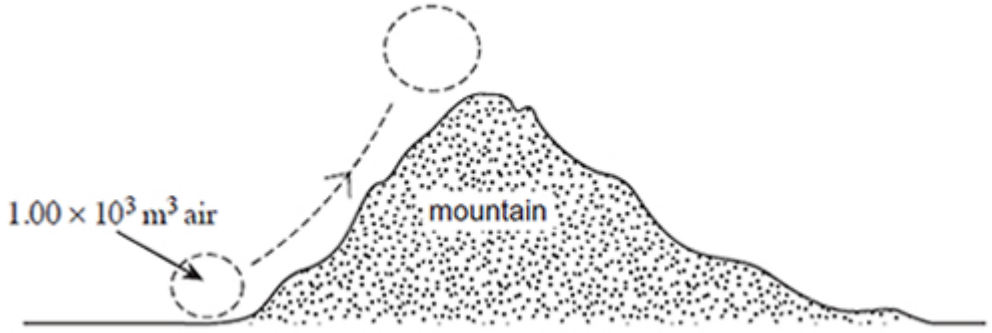
Q10.

This question is about a group of a fixed number of air molecules that remain together called an air pocket.

The diagram shows an air pocket of volume 1.00×10^3 m^3 near the base of a mountain where the temperature is 25°C and atmospheric pressure is 1.01×10^5 Pa. The air pocket

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expands adiabatically as it rises to the top of the mountain where the air pressure is lower.



(a) Calculate the new volume of the air pocket when it reaches the top of the mountain, where the pressure is 8.25×10^4 Pa.
Give your answer to an appropriate number of significant figures.

adiabatic index γ for air = 1.40

volume = _____ m^3

(3)

(b) Meteorologists use the term adiabatic lapse rate for the temperature change per km when air rises as it expands adiabatically.

Calculate the temperature of the air pocket when it has reached the top of the mountain, and hence estimate the height of the mountain assuming the adiabatic lapse rate is 9.8 K km^{-1}.

temperature = _____ °C

height = _____ km

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(3)

(c) Work is done by the air pocket as it expands against the surrounding air. Explain, with reference to the first law of thermodynamics, why the temperature of the air decreases as the air pocket rises.

(3)

(Total 9 marks)

Q11.

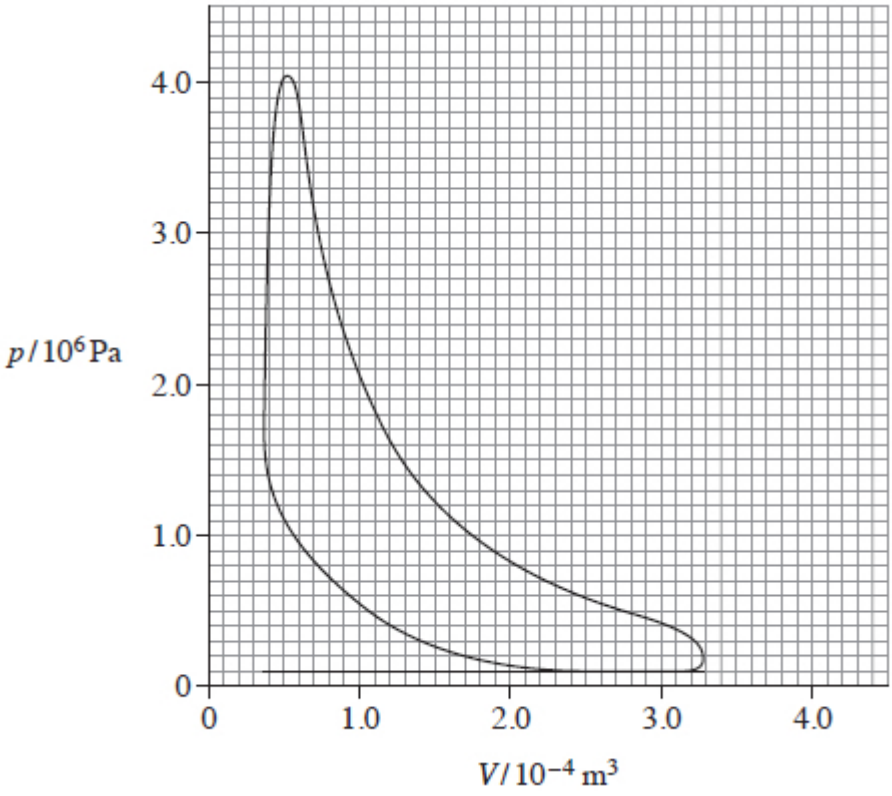
(a) Explain the **basic** differences in operation between a petrol engine and a diesel engine.

(2)

(b) **Figure 1** shows the indicator diagram taken during a test from one cylinder of a four cylinder four-stroke petrol engine.

Figure 1

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Data from the test are as follows:

engine speed: 2000 rev min^{-1}

calorific value of fuel: 44.0 MJ kg^{-1}

fuel consumption: 1.1 × 10^{-3} kg s^{-1}

(i) Draw an **X** on the graph to show where in the cycle the spark would occur.

(1)

(ii) Calculate the indicated power of the engine.

power = _____ W

(4)

(iii) Calculate the thermal efficiency of the engine.

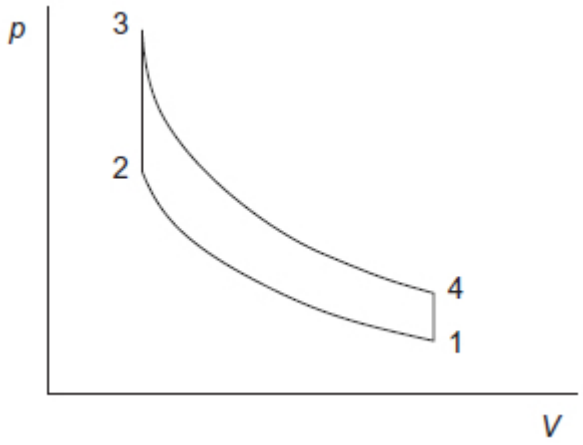
thermal efficiancy = _____

(2)

(c) **Figure 2** shows the *p* - *V* diagram for a theoretical or ideal petrol engine (Otto) cycle.

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Figure 2



Which **one** of the following lines in the table best represents what is occurring in different parts of the ideal cycle of **Figure 2**?
Place a tick (✓) in the right-hand column to show the correct answer.

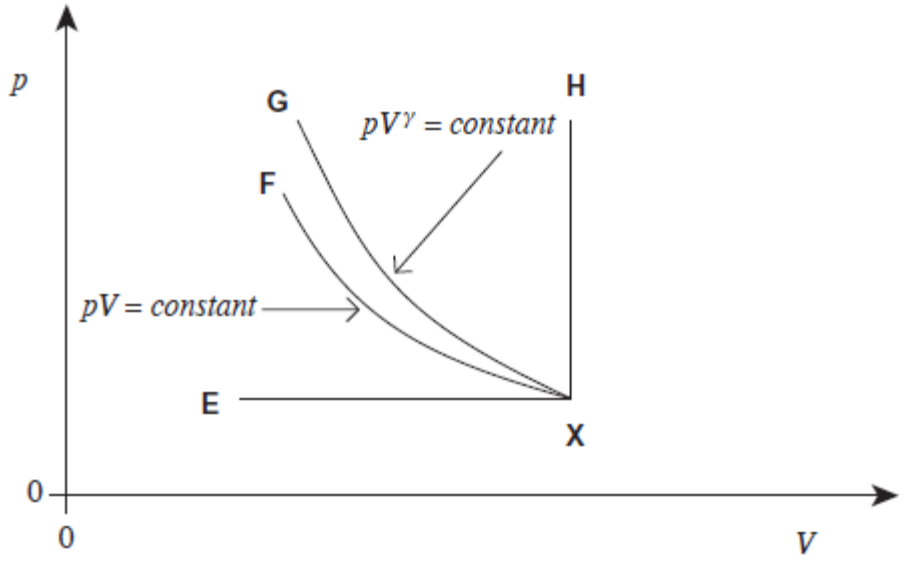
1 ⟶ 2	2 ⟶ 3	3 ⟶ 4	4 ⟶ 1	✓ if correct
induction	compression	expansion	exhaust	
comression	heating	expansion	cooling	
induction	heating	cooling	exhaust	
cooling	compression	heating	expansion	

(1)
(Total 10 marks)

Q12.

(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



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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**.

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work done _____ J

(3)

Figure 2

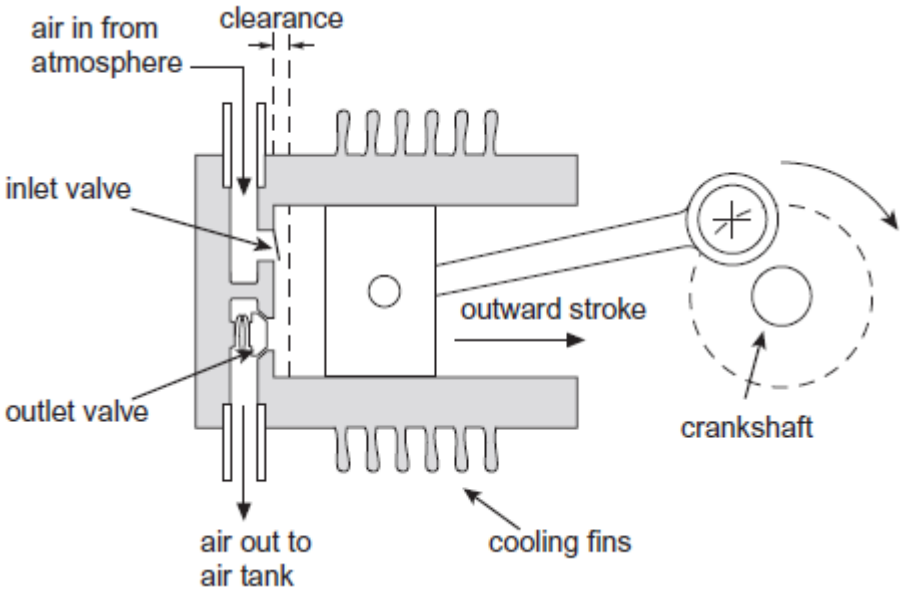
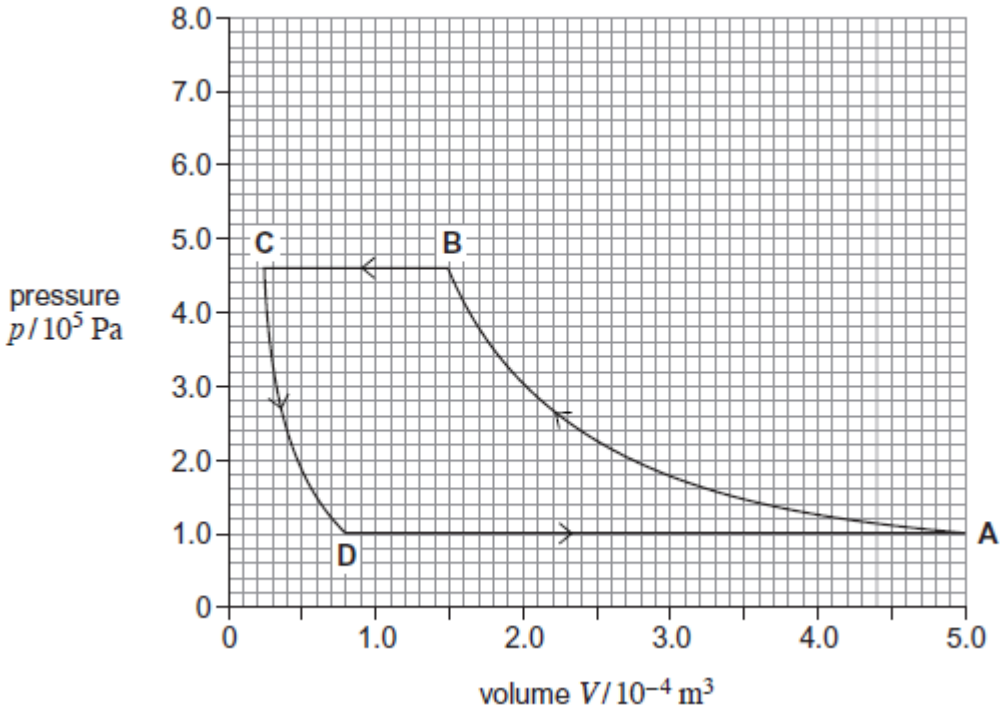


Figure 3



(iii) Determine the power input to the compressor when it runs at 420

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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.

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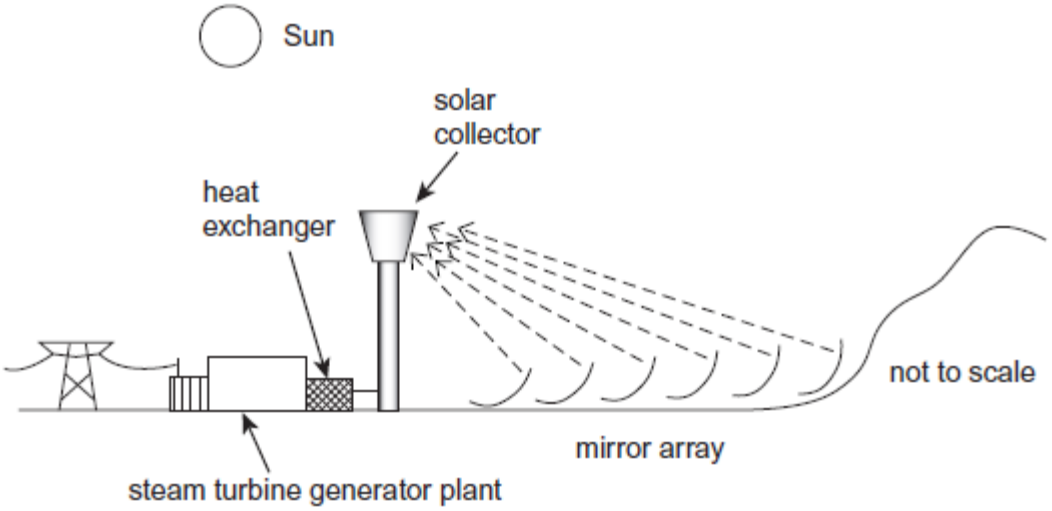
(6)

(Total 13 marks)

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Q13.

The diagram below shows the basic arrangement of a solar thermal power station. An array of mirrors tracks the Sun and reflects the Sun's rays onto a solar collector tower containing molten salt. The molten salt reaches a temperature of 540 °C. In the heat exchanger, the internal energy in the salt is transferred to water which turns to steam and drives a steam turbine generator to produce electricity. The steam turbine rejects energy to the atmosphere at 25 °C.



(a) Calculate the maximum theoretical efficiency of a heat engine operating between temperatures of 540 °C and 25 °C.

maximum efficiency = _____

(2)

(b) On one particular day the output of the power station is 48 MW. Calculate the input power to the power station assuming it can run at its maximum theoretical efficiency.

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input power = _____ W

(1)

(c) The actual efficiency of the steam turbine is about 38% when the molten salt is at 540 °C. State **two** reasons why the actual efficiency of the power station is much less than the maximum theoretical efficiency.

1. _____

_____

_____

2. _____

_____

_____

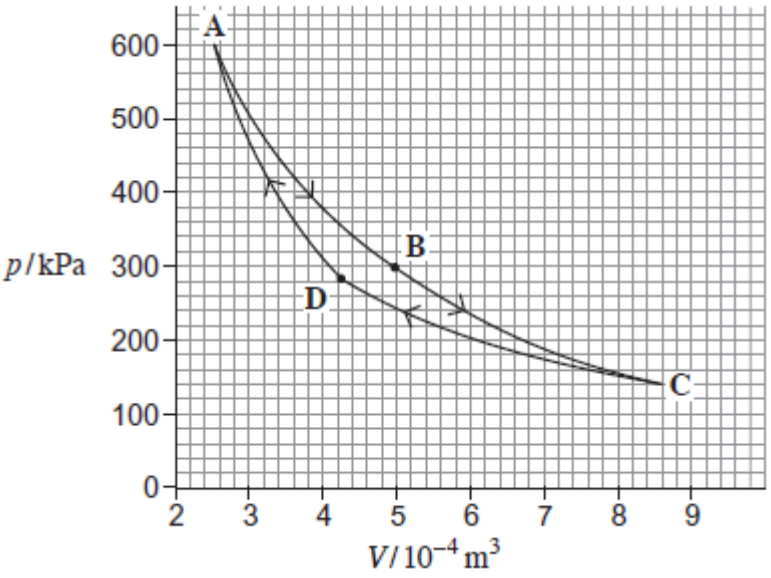
(2)

(Total 5 marks)

Q14.

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.

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(3)

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

_____

_____

_____

_____

_____

(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}

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volume flowing in one second _____ m^3

(3)

(Total 14 marks)

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Q1.

(a) Energy is supplied to the air by heating only in process 2 → 3 ✓

Automarked

1

(b) Claim A: Each square represents 10 J ✓
Area of loop 4 → 5 → 1 → 4 = 9 squares
Giving increase in work done = 90 J ✓

Claim B: area enclosed by loop 1 → 2 → 3 → 4 → 1 = 55 sq /550 J ✓
(Each square represents 10 J)
Increase in efficiency = 9 sq/55 sq or 90 J/550 J = 16% ✓
So claim A not met, claim B efficiency better than claimed ✓

OR Claim B:
Area enclosed by loop 1 → 2 → 3 → 4 → 1 = 55 sq /550 J ✓
Divides 550 J and 640 J by any same value for (heat) input energy
And calculates increase in efficiency ✓
Draws correct conclusion for A and B for answers ✓

W done per square = $0.1 \times 10^{-3} \times 1.00 \times 10^{5} = 10$ J

Allow 8 to 11 squares giving 80J to 110 J

Accept answers where area 4 → 5 → 1 → 4 is approximated to a triangle giving 112(.5) J

Allow 50 to 60 squares giving 500 to 600 J

ECF from above areas if out of tolerance

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