A-Level Physics

The p-V Diagram

Question Paper

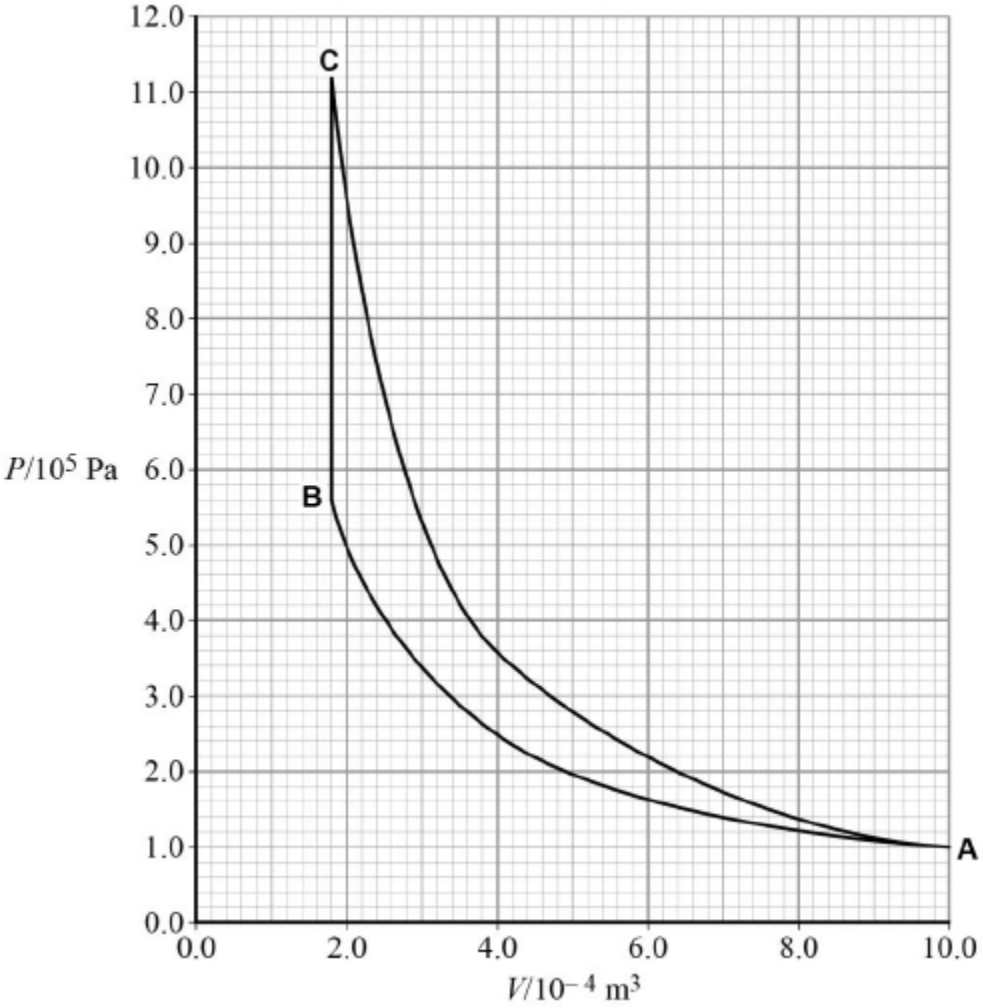
Time available: 114 minutes
Marks available: 60 marks

1. 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 $\times 10^5$ Pa and temperature 295 K is taken through the following stages in turn:

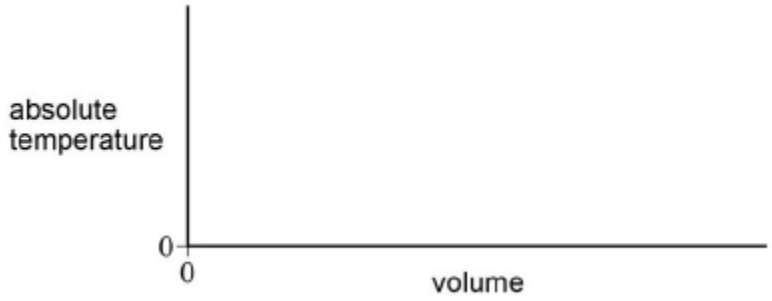
A ⟶ **B** isothermal compression

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)

(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.

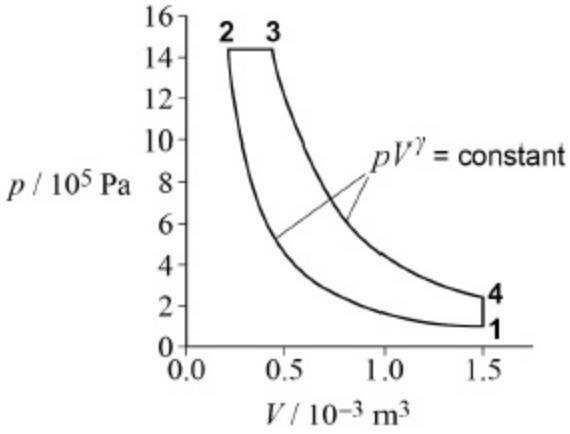
Discuss some of the problems that will have to be overcome. Go on to discuss, with reference to the power output and efficiency of the cycle, whether the engineer should go ahead with the design.

(6)

(Total 12 marks)

2. **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**. ☐

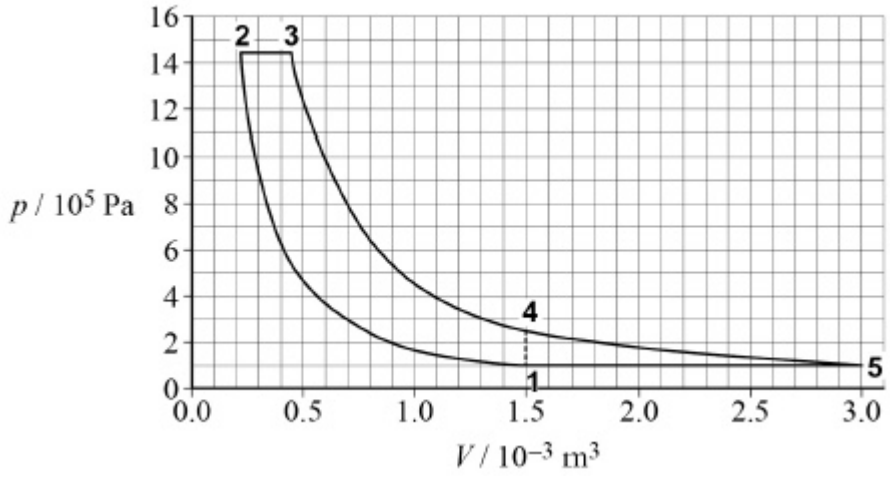
The area enclosed by the loop **1** → **2** → **3** → **4** → **1** is the power output of the cycle. ☐

(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



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

(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.

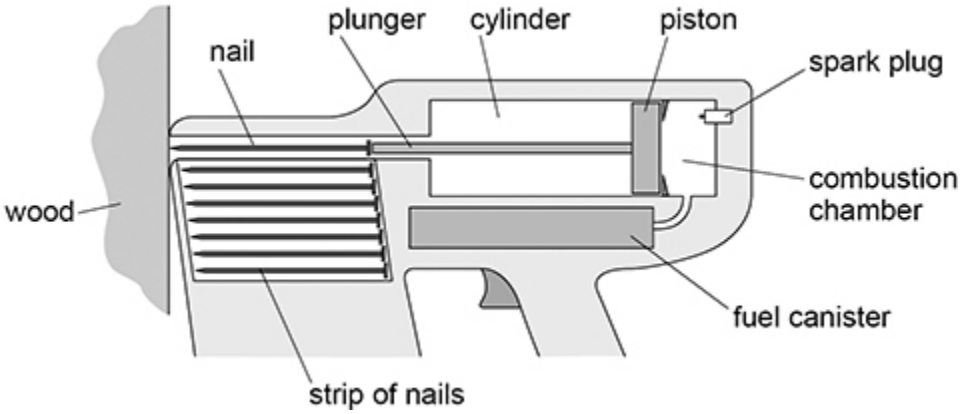
maximum temperature = _____ K

(3)

(Total 13 marks)

3. **Figure 1** shows a tool for driving nails into wood. Only part of the tool is shown.

Figure 1



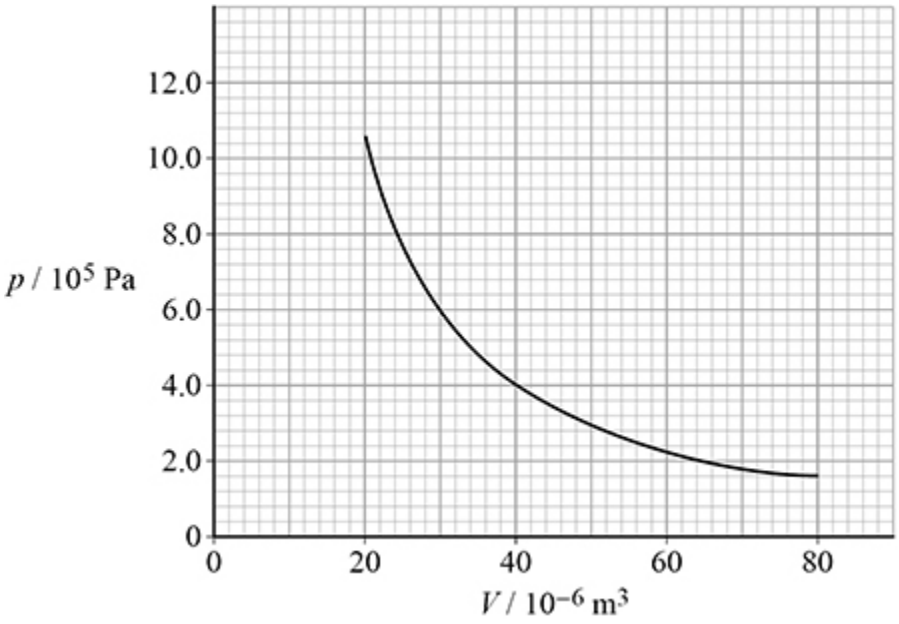
Fuel is mixed with air in the combustion chamber and is ignited by a spark. The gas expands rapidly and drives the piston along the cylinder. The plunger attached to the piston drives the nail into the wood.

The table below shows the average force needed to drive nails of various lengths completely into a particular type of wood.

Nail	Length / mm	Average force / N
A	32	250
B	38	320
C	45	370
D	50	420
E	63	560

(a) **Figure 2** shows the variation of pressure p with volume V as the gas expands on the right-hand side of the piston when the correct nail is used.

Figure 2



The combustion chamber has a volume of 20×10^{-6} m^3 and the piston moves through a volume of 60×10^{-6} m^3.

The work done by the expanding gas is just enough to drive the correct nail completely into the wood.

Deduce which nail in the table above is the correct one to use in the tool.

(5)

(b) After a nail has been used, another nail takes its place automatically. The tool can drive up to 180 nails per minute.

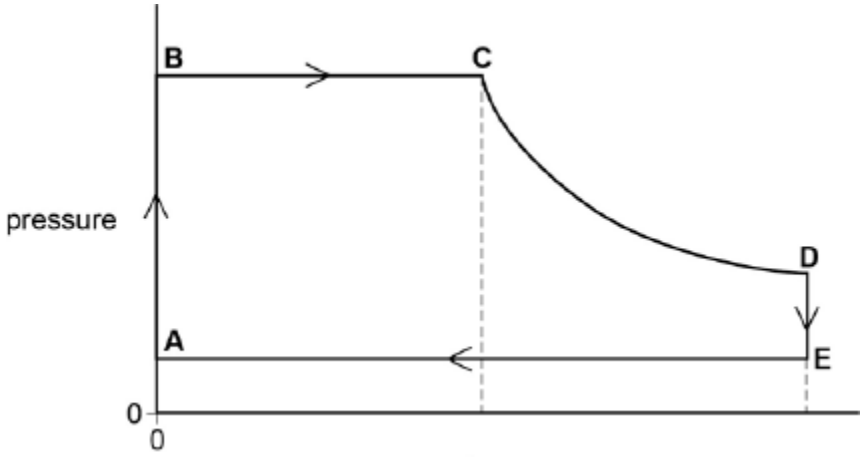
Discuss why the expansion **cannot** be isothermal.

(3)

(Total 8 marks)

4. A single-cylinder air motor running on compressed air has the theoretical indicator diagram shown in **Figure 1**.

Figure 1



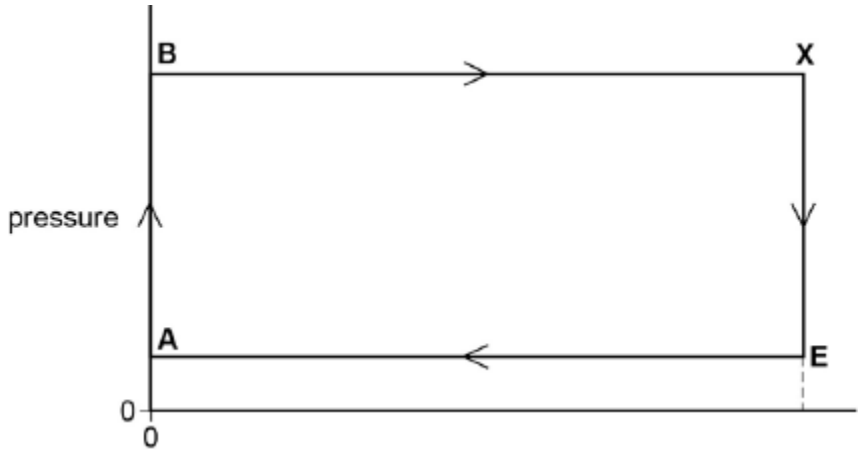
- From **B** to **C** the high-pressure air pushes a piston down a cylinder, doing work.
- At **C**, a valve cuts off the supply of air and the air in the motor expands adiabatically to D, pushing the piston further down the cylinder.
- At **D** an exhaust valve opens and from **D** to **E** to **A** the air is exhausted to the surrounding atmosphere as the piston moves up the cylinder.
- At **A** the exhaust valve closes and the inlet valve opens connecting the cylinder to the supply of compressed air.

(a) Use the first law of thermodynamics to explain why the temperature falls during the adiabatic change between **C** and **D**.

(3)

(b) In practice the cut-off point **C** can be altered without changing points **A**, **B** and **E**.
Figure 2 shows the theoretical indicator diagram of the motor when the air is admitted for the complete stroke, so that the inlet valve opens at **A** and closes at **X**. The exhaust valve opens at **X** and closes at **A**.

Figure 2



Compare **Figures 1** and **2** and discuss the effect this change has on the operation of the motor, assuming that it continues to run at about the same speed and with air at the same pressure.

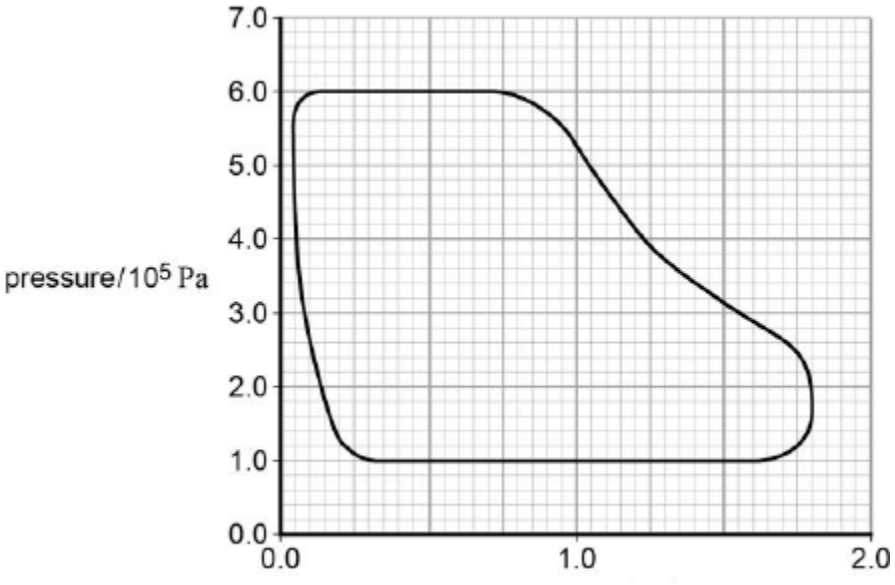
You should include in your answer how the change affects:

- the rate of consumption of air
- the output torque and power
- the overall efficiency.

(6)

Figure 3 shows the actual indicator diagram for the air motor.

Figure 3



(c) The motor was running at 20 cycles per second when the indicator diagram was recorded.

Determine the indicated power of the motor.

power = _____ W

(4)

(d) Explain why the indicated power for the air motor is different from the output power.

_____

_____

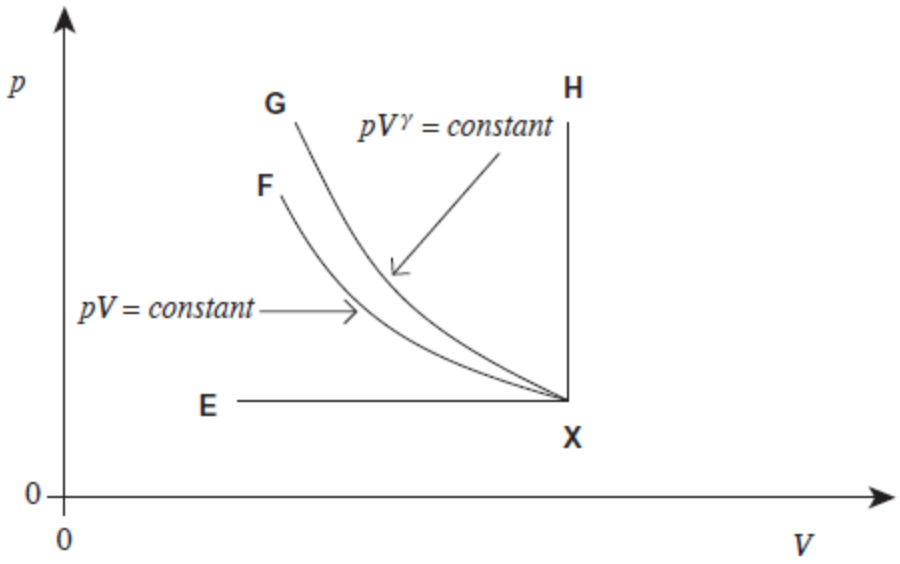
_____

(1)

(Total 14 marks)

5. (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

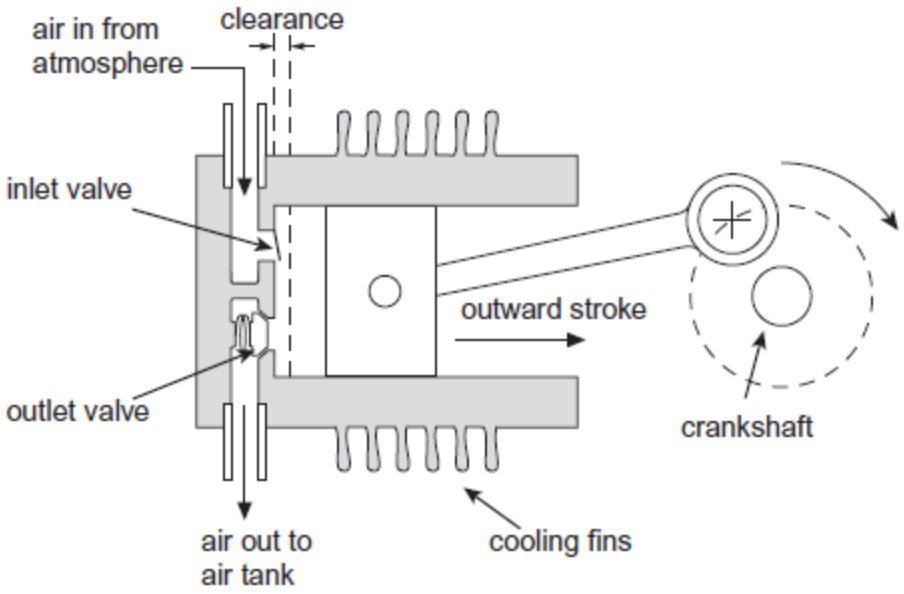
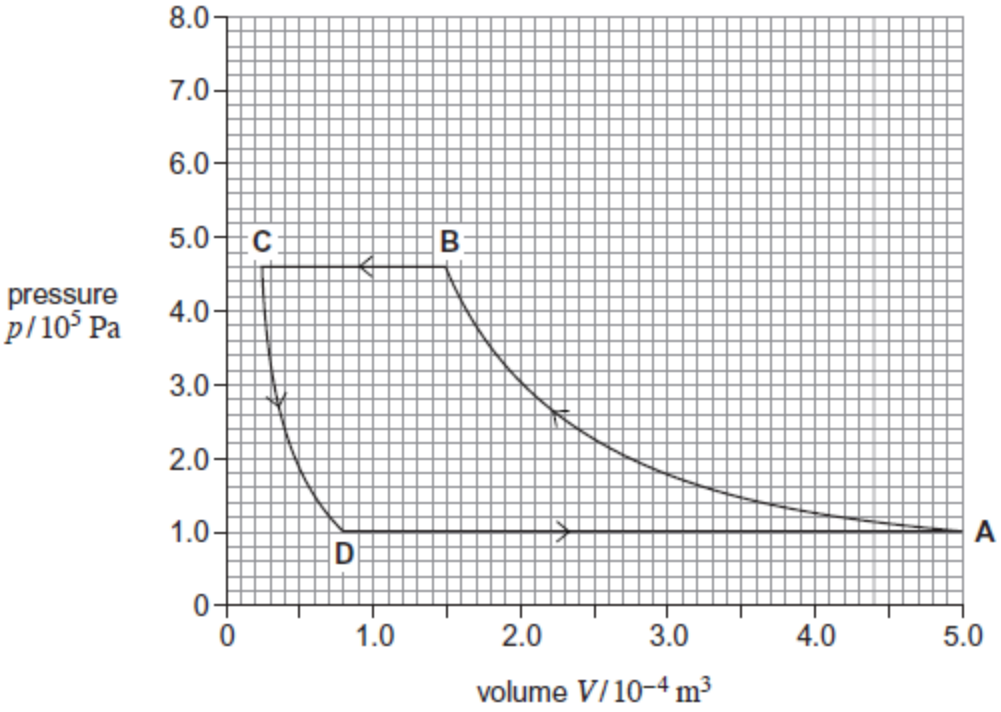


Figure 3



(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)