Additional examination-style questions

1 **Figure 1** shows a remote-control camera used in space for inspecting space stations. The camera can be moved into position and rotated by firing thrusters which eject xenon gas at high speed. The camera is spherical with a diameter of 0.34 m. In use, the camera develops a spin about its axis of rotation. In order to bring it to rest, the thrusters on opposite ends of a diameter are fired, as shown in **Figure 1**.

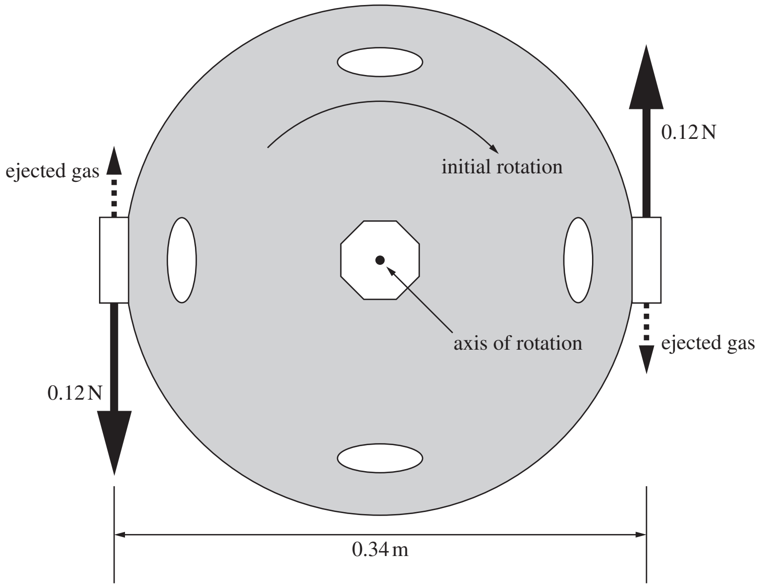


Figure 1

(a) When fired, each thruster provides a constant force of 0.12 N.

(i) Calculate the torque on the camera provided by the thrusters.

(ii) The moment of inertia of the camera about its axis of rotation is 0.17 kg m^2. Show that the angular deceleration of the camera whilst the thrusters are firing is 0.24 rad s^{-2}. *(3 marks)*

(b) The initial rotational speed of the camera is 0.92 rad s^{-1}. Calculate

(i) the time for which the thrusters have to be fired to bring the camera to rest,

(ii) the angle turned through by the camera whilst the thrusters are firing. Express your answer in degrees. *(3 marks)*

AQA 2006

2 Flywheels store energy very efficiently and are being considered as an alternative to battery power.

(a) A flywheel for an energy storage system has a moment of inertia of 0.60 kg m^2 and a maximum safe angular speed of 22 000 rev min^{-1}. Show that the energy stored in the flywheel when rotating at its maximum safe speed is 1.6 MJ. *(2 marks)*

(b) In a test the flywheel was taken up to maximum safe speed and then allowed to run freely until it came to rest. The average power dissipated in overcoming friction was 8.7 W. Calculate

(i) the time taken for the flywheel to come to rest from its maximum speed,

(ii) the average frictional torque acting on the flywheel. *(2 marks)*

(c) The energy storage capacity of the flywheel can be improved by adding solid discs to the flywheel as shown in cross-section in **A** in **Figure 2**, or by adding a hoop or tyre to the rim of the flywheel as shown in **B** in **Figure 2**. The same mass of material is added in each case. State, with reasons, which arrangement stores the more energy when rotating at a given angular speed.

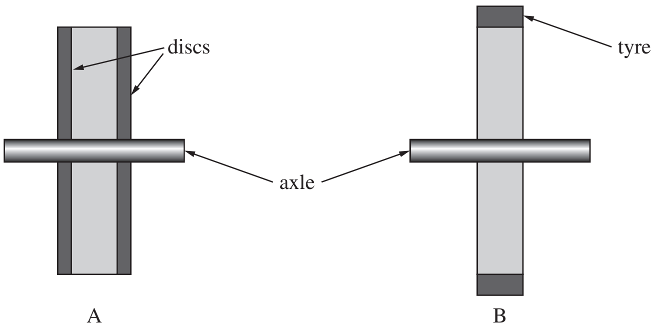


Figure 2 *(2 marks)*

AQA 2006

3 A swing bridge carries road traffic over a river. To allow movement of river boats, the bridge opens by turning through an angle of 90° in a time of 80 seconds. **Figure 3** shows plan views of the bridge in closed and open positions.

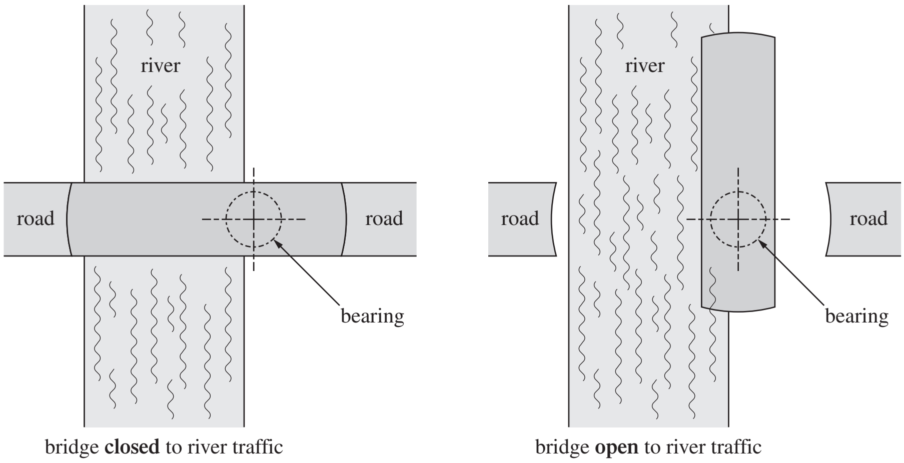
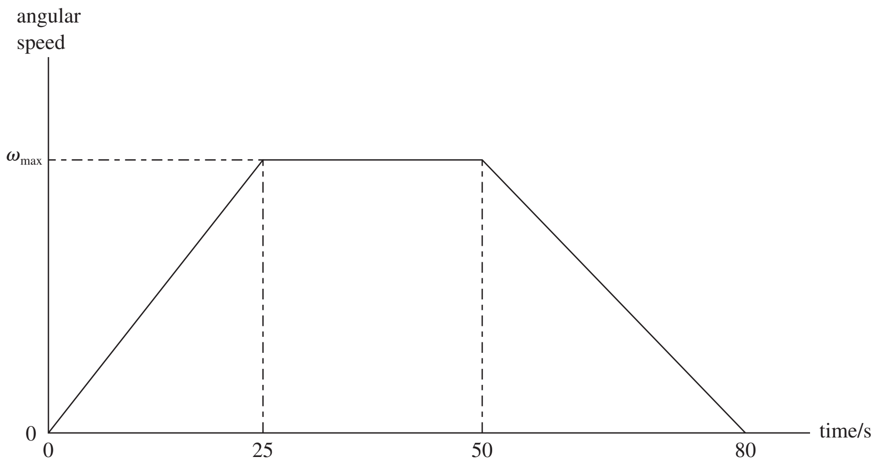


Figure 3

The graph below shows the variation of angular speed of the bridge from fully closed to fully open. The bridge accelerates, moves at constant angular speed and then decelerates to a standstill.



(a) **(i)** Show that the maximum angular speed, ω_{max}, of the bridge is 0.030 rad s^{-1}.

(ii) Calculate the angular acceleration of the bridge in the first 25 s. *(3 marks)*

(b) The moment of inertia of the bridge about its axis of rotation is 9.1×10^8 kg m^2. When the bridge is moving, a constant frictional torque of 3.5×10^5 N m acts to oppose its motion. Calculate

(i) the torque that must be applied by the driving motor of the bridge to give the bridge the angular acceleration calculated in part **(a)(ii)**,

(ii) the power output of the driving motor to keep the bridge moving at constant angular speed between 25 s and 50 s,

(iii) the maximum kinetic energy of the bridge. *(4 marks)*

AQA 2007

4 **Figure 4** shows a friction clutch which enables an electric motor to be easily connected to and disconnected from a flywheel. When the motor needs to be connected to the flywheel the discs are forced into contact and slipping occurs for a short time until the motor and flywheel rotate at a common angular speed. The clutch is then said to be engaged.

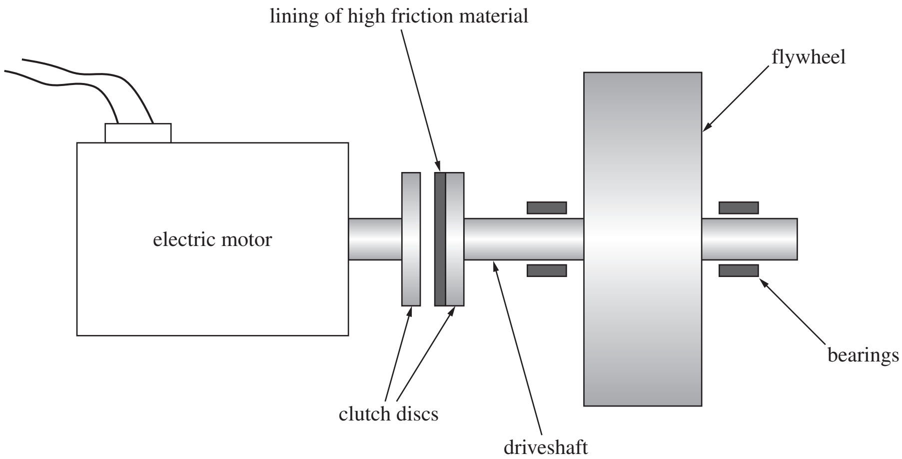


Figure 4

(a) The flywheel is initially stationary and the motor is rotating at 1500 rev min^{-1}. The rotating parts (the rotor and clutch disc) of the electric motor have a moment of inertia of 0.56 kg m^2. Calculate the angular momentum of the motor. *(2 marks)*

(b) The motor is now connected by means of the clutch to the flywheel. The moment of inertia of the flywheel and driveshaft is 0.94 kg m^2.

(i) Explain why the speed of the motor falls as the clutch engages.

(ii) Calculate the common angular speed of the motor and flywheel immediately after the clutch is engaged. *(3 marks)*

AQA 2007

5 **Figure 5** shows a small gyroscope. A heavy disc is mounted on an axle which is supported by a rigid circular frame. A length of string is wrapped around the axle and is pulled with a constant force, accelerating the disc until the string is completely unwrapped and falls away from the axle. With the disc rotating at high speed the properties of a gyroscope can be demonstrated.

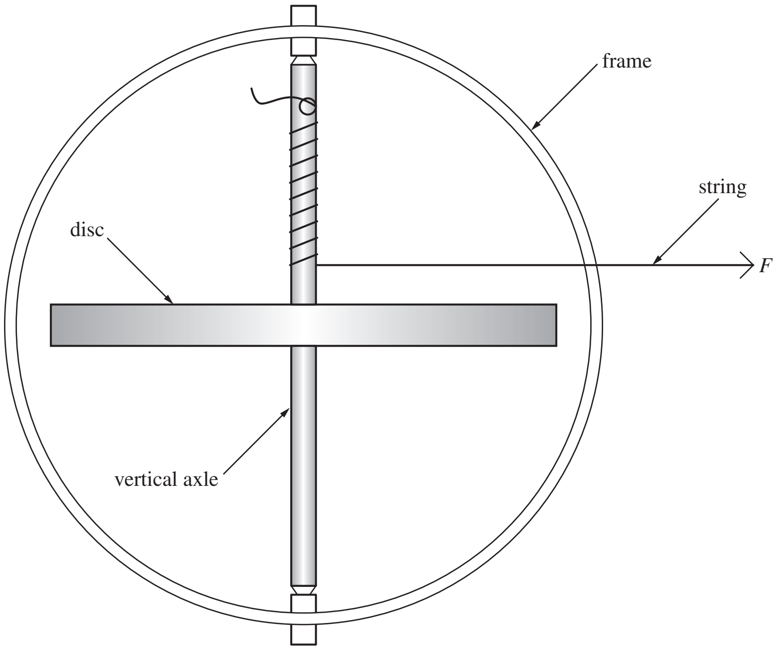


Figure 5

moment of inertia of the flywheel and axle about its axis = 1.8×10^{-4} kg m^2
axle diameter = 4.0 mm

(a) The string is wrapped 30 times around the axle. Measurements show that it takes 2.1 s for the string to unwind from rest.

(i) Show that the angular acceleration of the disc and axle is 85 rad s^{-2}.

(ii) The maximum angular speed is reached when the string leaves the axle. Calculate this speed.

(iii) Neglecting friction at the bearings, calculate the pulling force F. *(5 marks)*

(b) After the string left the axle it took 72 s for the disc to come to rest. This shows that there is a small frictional torque acting at the bearings. Calculate this frictional torque. *(1 mark)*

AQA 2008

6 **Figure 6** shows the basic drive system of a hand-driven sewing machine. During one revolution the torque on the driveshaft varies because of the varying force on the needle when a stitch is made.

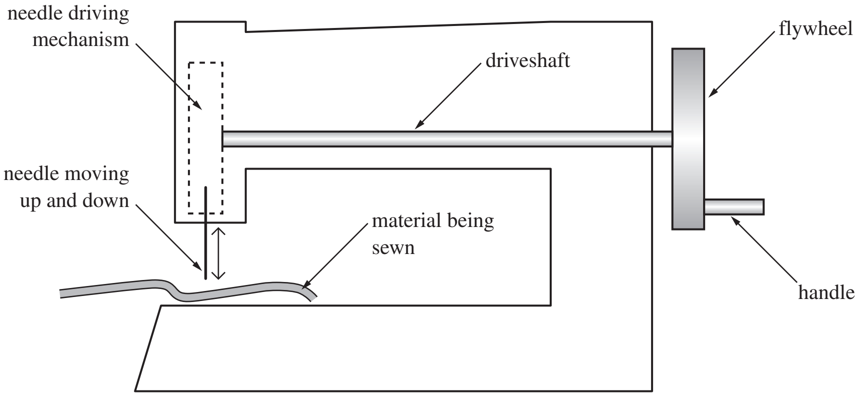


Figure 6

(a) Explain the function of the flywheel.
You may be awarded marks for the quality of written communication in your answer. *(2 marks)*

(b) The moment of inertia of the flywheel about its axis is 3.7×10^{-3} kg m^2. Before a stitch is made the angular speed of the driveshaft is 14 rad s^{-1}. Calculate the rotational kinetic energy of the flywheel when rotating at this speed. *(1 mark)*

(c) After the handle is released a stitch is made, and the kinetic energy of the flywheel is reduced by 0.082 J. Calculate the angular speed of the flywheel immediately after the stitch is made. *(3 marks)*

AQA 2008

7 **Figure 7** shows a device for demonstrating an effect of adiabatic compression. A small pad of dry cotton wool is placed on the metal plug at the lower end of a long transparent plastic tube. The plunger is pushed quickly down the tube compressing the air in the tube. When the plunger nears the bottom the cotton wool is seen to ignite in a small tongue of flame.

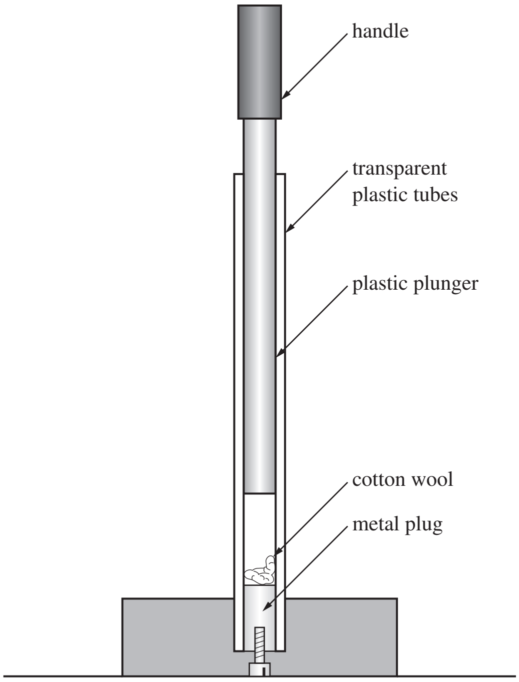


Figure 7

(a) With the plunger at the top of the tube the air inside the tube has a volume of 1.2×10^{-5} m^3 and is at atmospheric pressure of 1.0×10^5 Pa. When the plunger has been pushed down the tube to its lowest point, the volume of air in the tube is 3.1×10^{-7} m^3. Assuming the compression of the air to be adiabatic, show that the pressure of air in the tube is 1.7×10^7 Pa. γ for air = 1.4. *(2 marks)*

(b) The temperature of the air before the compression is 290 K. Calculate

(i) the number of moles of air in the tube,

(ii) the temperature of the air at the end of the compression. *(4 marks)*

(c) Use the first law of thermodynamics to explain why the cotton wool will not ignite if the plunger is pushed down the tube very slowly.
You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer. *(3 marks)*

AQA 2006

8 The ram jet engine was used as a cheap and efficient propulsion unit for high speed guided missiles. **Figure 8** shows a section through this engine.

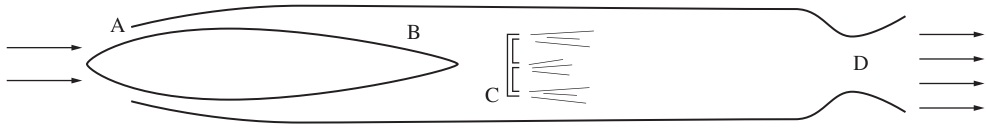
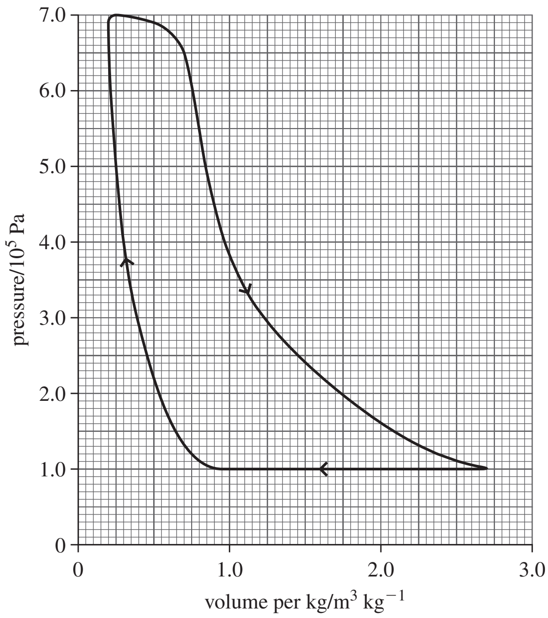


Figure 8

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.

(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.

(iii) Because of the high speed of the air in the engine, there is significant frictional heating amounting to a power loss of 430kW. Determine the power output of the engine (available for thrust). *(5 marks)*

(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,

(ii) the overall efficiency of the engine. *(2 marks)*

AQA 2006

9 Wood chips are burned in a power plant to produce steam that drives turbine generators to generate electricity. Fast-growing trees are specially grown for this purpose. The power plant has an efficiency of 24%.

(a) Calculate the energy input to the power plant to give a daily electrical energy output of 1.30×10^{11} J. *(1 mark)*

(b) The calorific value of the wood chips is 10.4 MJ kg^{-1}. Calculate the daily mass of wood chips required. *(1 mark)*

(c) The maximum temperature of the steam is 420 °C and the minimum temperature is 10 °C.

(i) Calculate the maximum theoretical efficiency of a heat engine operating between these temperatures.

(ii) State **one** reason why in practice the power plant has a lower efficiency than your answer to part **(c)(i)**.

(iii) State **one** advantage of wood grown for fuel instead of oil or coal to produce steam for the power plant, even though the wood-fuelled power plant may be less efficient. *(4 marks)*

AQA 2007

10 (a) The *p*-*V* diagram in **Figure 9** shows the theoretical cycle for a petrol engine in which a fixed mass of air is taken through the following four processes:
A → B adiabatic compression from an initial temperature of 293 K
B → C addition of 700 J of energy at constant volume
C → D adiabatic expansion
D → A reduction in pressure at constant volume.

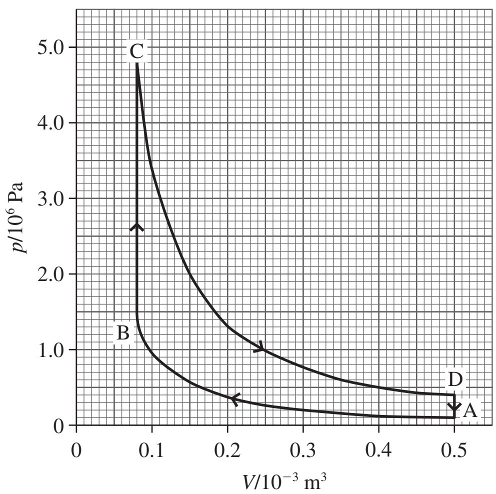


Figure 9

(i) Apply the first law of thermodynamics to determine the change in internal energy of the air in process B → C.

(ii) Show that 0.021 mol of air are taken through the cycle.

(iii) Determine the work output of the cycle. *(6 marks)*

(b) **Figure 10** shows the *p*-*V* diagram taken from a real four-stroke petrol engine having the same maximum and minimum volumes as the cycle shown in **Figure 9**.

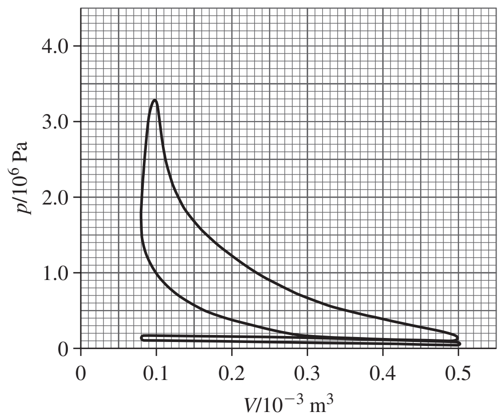


Figure 10

Explain **two** differences between the theoretical and real cycles (as illustrated by **Figures 9** and **10**). You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer. *(2 marks)*

AQA 2007

11 (a) (i) Explain what is meant by the *adiabatic compression* of a gas.

(ii) Explain why the compression stroke of a diesel engine can be considered to be adiabatic. *(2 marks)*

(b) **Figure 11** shows part of an ideal diesel engine cycle in which a constant mass of air is compressed adiabatically, A → B, and is then heated at constant pressure, B → C.

adiabatic index, γ, for air = 1.4

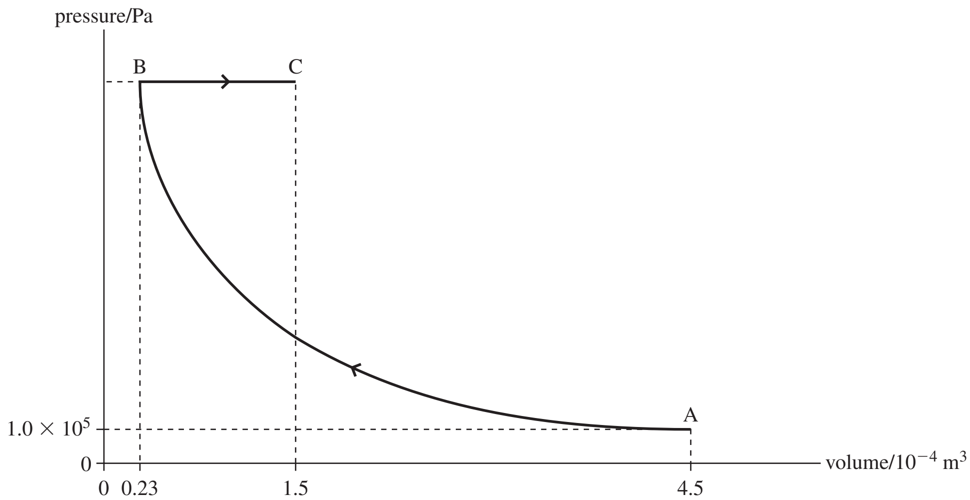


Figure 11

(i) Calculate the pressure at B.

(ii) Apply the first law of thermodynamics to complete the gaps in the table.

	ΔW/J	ΔQ/J	ΔU/J
A → B	−255		
B → C		2860	

(5 marks)
AQA 2008

12 'Atmospheric' engines were once used to pump water out of mines. These engines operated on the following cycle:

- the weight of the pump rod raised the piston and at the same time steam was admitted to the cylinder (see **Figure 12**)
- the steam valve was closed and the water valve opened, allowing a jet of cold water into the cylinder to condense the steam. This created a partial vacuum. Atmospheric pressure forced the piston down, lifting the pump rod and raising water from the mine (see **Figure 13**)
- when the piston was at the bottom of its stroke, the drain valve was opened to let the condensed steam and cooling water out of the cylinder.

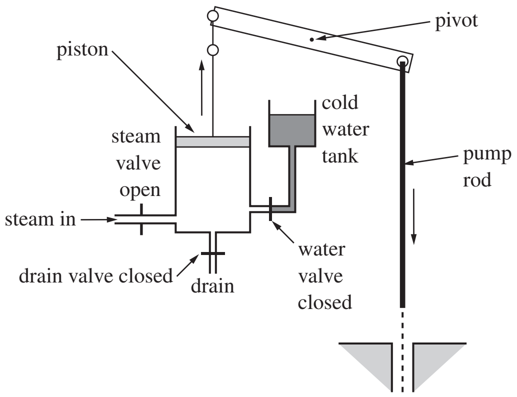


Figure 12

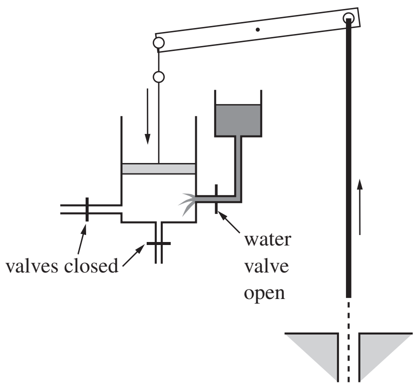


Figure 13

The *p*-*V* diagram for one particular atmospheric engine is shown in **Figure 14**.

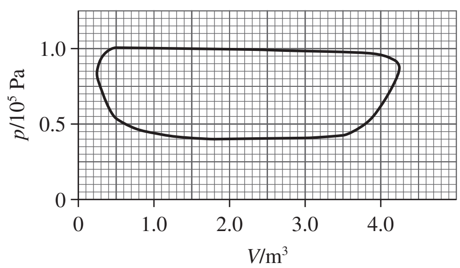


Figure 14

(a) **(i)** Use Figure 14 to determine the indicated work done by the engine in one cycle.

(ii) It took 6.0 seconds for the engine to complete one cycle. Calculate the indicated power of the engine. *(4 marks)*

(b) In each cycle a mass of 7600 kg of water was raised a height of 1.8 m. Determine for this engine

(i) the output power,

(ii) the mechanical efficiency. *(2 marks)*

(c) The temperature of the steam was 103 °C (376 K) and the cooling water was at 15 °C (288 K).

(i) Calculate the maximum theoretical efficiency of a heat engine operating between these temperatures.

(ii) The actual overall efficiency of the engine was less than 1%. Suggest **two** reasons why the efficiency of the engine was so very low. *(3 marks)*

AQA 2008