SPECIMEN MATERIAL

A-level
PHYSICS
(7408/3BC)

Paper 3 – Section B (Engineering Physics)

Specimen 2014 | Morning | Time allowed: 2 hours

Materials
For this paper you must have:
- a pencil
- a ruler
- a calculator
- a data and formulae booklet
- a question paper / answer book for Section A.

Instructions
- Answer **all** questions.
- Show all your working.
- The total time for both sections of this paper is 2 hours.

Information
- The maximum mark for this section is 35.

Please write clearly, in block capitals, to allow character computer recognition.

Centre number ☐☐☐☐☐ Candidate number ☐☐☐☐

Surname

Forename(s)

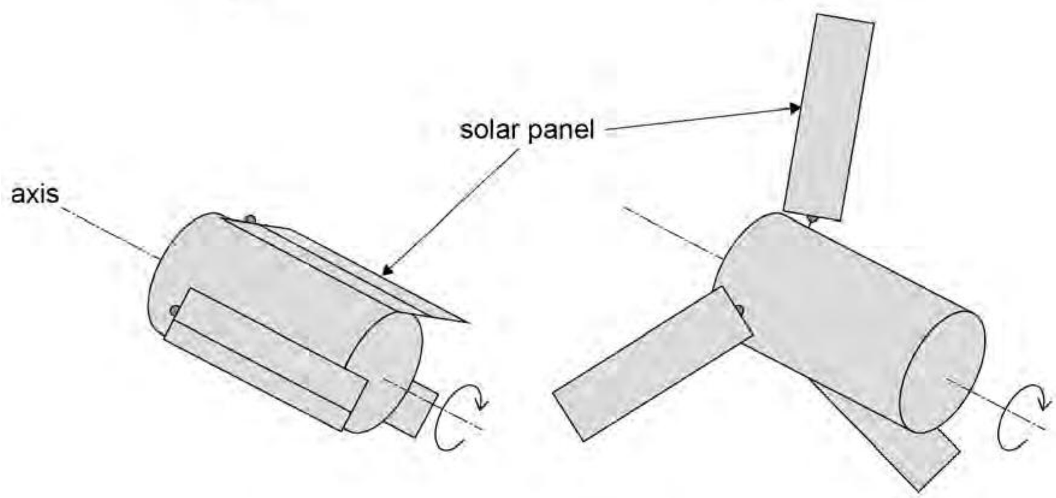
Candidate signature ____________________

Section B

Answer **all** questions in this section.

0 1 **Figure 1** shows a satellite with three solar panels folded in close to the satellite's axis for the journey into space in the hold of a cargo space craft.

Figure 1 **Figure 2**



Just before it is released into space, the satellite is spun to rotate at 5.2 rad s^{-1}. Once released, the solar panels are extended as shown in **Figure 2**.

moment of inertia of the satellite about its axis with panels folded = 110 kg m^2
moment of inertia of the satellite about its axis with panels extended = 230 kg m^2

0 1 . 1 State the law of conservation of angular momentum.

[1 mark]

The total ~~linear~~ angular momentum of a system remains constant, provided no external ~~force~~ torque acts on the system.

linear → angular force → torque

0 1 . 2 The total mass of the satellite is 390 kg and the solar panels each have a mass of 16 kg.

State what is meant by moment of inertia and explain why extending the solar panels changes the moment of inertia of the satellite by a large factor.

$I = mr^2$

[3 marks]

• Moment of inertia is the sum of every mr^2 for each point mass in the body consists of, at radius r ✓
• Some of the satellite's mass moves to a larger radius ✓
• r is squared, so a small r increase gives a large I increase ✓

0 1 . 3 Calculate the angular momentum of the satellite when it is rotating at 5.2 rad s^{-1} with the solar panels folded. State an appropriate unit for your answer.

($p = mv$)

[2 marks]

$\omega = 5.2 \text{ rad s}^{-1}$

$L = I\omega$ — angular velocity

angular momentum — moment of inertia

$I = 110 \text{ kgm}^2$

$110 \times 5.2 = 572$

angular momentum = 572 ✓ unit $\text{kgm}^2\text{rads}^{-1}$ ✓

OR Nms OR $\text{kgm}^2\text{s}^{-1}$

0 1 . 4 Calculate the angular speed of the satellite after the solar panels have been fully extended.

[2 marks]

$\omega = ?$ $\quad L = I\omega$

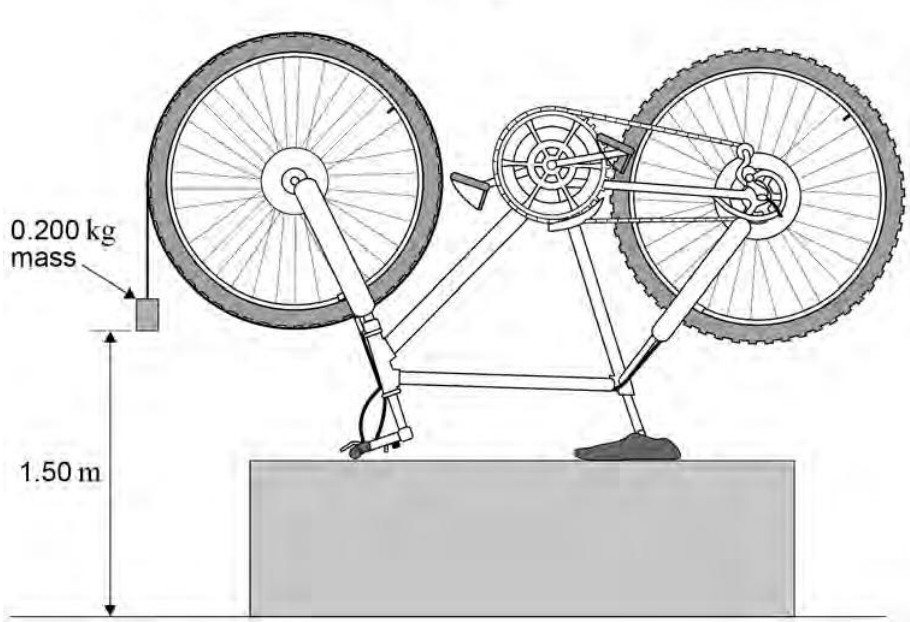
$\omega = \frac{L}{I} = \frac{572}{230}$ ✓ $= 2.4896$

$\simeq 2.49$

angular speed = 2.49 ✓ rad s^{-1}

0 2 **Figure 3** shows an experiment to determine the moment of inertia of a bicycle wheel. One end of a length of strong thread is attached to the tyre. The thread is wrapped around the wheel and a 0.200 kg mass is attached to the free end. The wheel is held so that the mass is at a height of 1.50 m above the floor. The wheel is released and the time taken for the mass to reach the floor is measured.

Figure 3



0 2 . 1 State the energy transfers that take place from the moment the wheel is released until the mass hits the floor.

[2 marks]

• The mass loses gravitational potential energy as it moves towards the floor

→ Increases rotational kinetic energy of wheel and linear kinetic energy of mass ✓

→ Air resistance causes the internal energy of the air to increase and friction increases the internal energy of the wheel bearing ✓

0 2 . 2 Calculations based on the measurements made show that at the instant the mass hits the floor:

- the speed of the mass is 2.22 $m\ s^{-1}$
- the wheel is rotating at 6.73 $rad\ s^{-1}$
- the wheel has turned through an angle of 4.55 rad from the point of release.

$KE = \frac{1}{2}mv^2$

$RKE = \frac{1}{2}I\omega^2$

$W = T\theta$

A separate experiment shows that a constant frictional torque of 7.50×10^{-3} N m acts on the wheel when it is rotating.

By considering the energy changes in the system, show that the moment of inertia of the wheel about its axis is approximately 0.1 $kg\ m^2$.

[3 marks]

$\Delta GPE = \Delta KE + \Delta RKE + W$

work done against friction

change in gravitational potential energy

change in linear kinetic energy

change in rotational kinetic energy

$mg\Delta h = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + T\theta$ ✓✓

$\Rightarrow I = \dfrac{mg\Delta h - \frac{1}{2}mv^2 - T\theta}{\frac{1}{2}\omega^2}$

$I = \dfrac{(0.200 \times 9.81 \times 1.50) - (0.5 \times 0.200 \times 2.22^2) - ((7.50 \times 10^{-3}) \times 4.55)}{0.5 \times 6.73^2}$ ✓

$= 0.107\ kgm^2$

$\simeq 0.1\ kgm^2$

0 2 . 3 When the mass hits the floor the thread is released from the wheel.

Calculate the angle turned through by the wheel before it comes to rest after the thread is released.

[2 marks]

$F = ma$

resultant force

mass

linear acceleration

$v^2 = u^2 + 2as$

$\omega_f^2 = \omega_i^2 + 2\alpha\theta$

$= \omega_i^2 + 2\left(\frac{T}{I}\right)\theta$ ✓

$T = I\alpha$

torque

moment of inertia

angular acceleration

$\theta = \dfrac{\omega_f^2 - \omega_i^2}{2\left(\frac{T}{I}\right)} = \dfrac{-\omega_i^2}{2\left(\frac{T}{I}\right)}$

$= \dfrac{-6.73^2}{2\left(\frac{-7.5 \times 10^{-3}}{0.107}\right)} = 323\ rad$

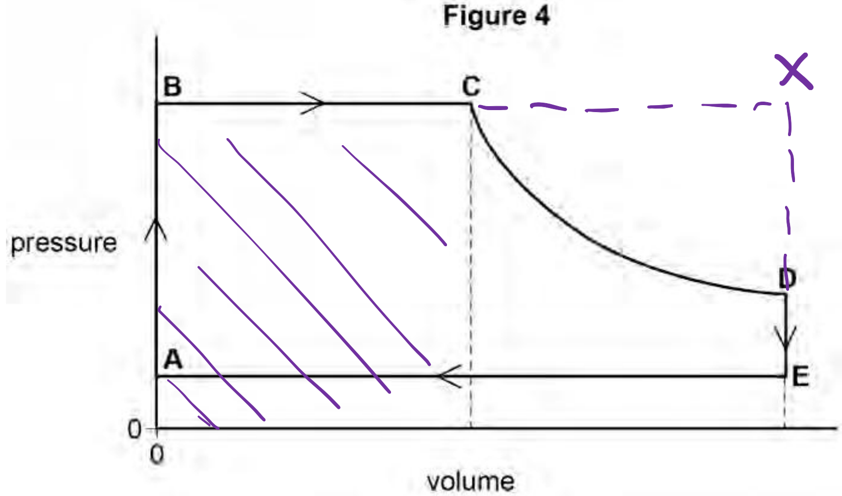
angle = 323 ✓ rad

Alternative

$\frac{1}{2}I\omega^2 = T\theta$

0 3 A single-cylinder air motor running on compressed air has the theoretical indicator diagram shown in **Figure 4**.

Figure 4



- 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.

0 3 . 1 Use the first law of thermodynamics to explain why the temperature falls during the adiabatic change between **C** and **D**.

[3 marks]

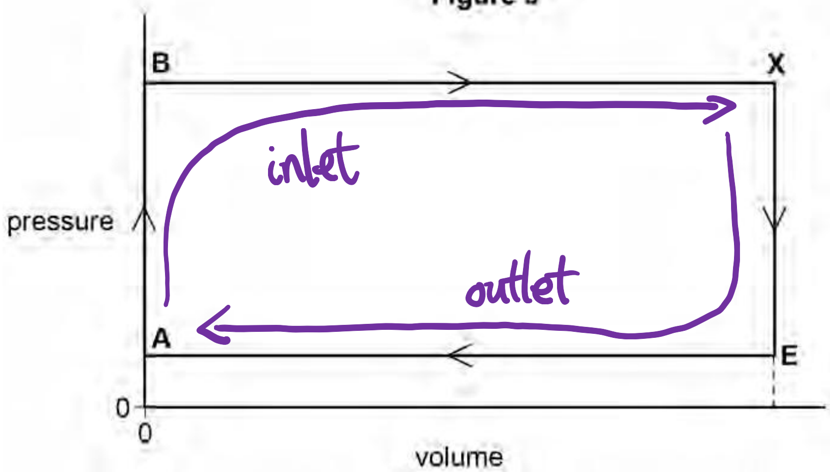
$\Delta U = Q - W$ → work done by system

ΔU: internal energy; Q: heat transferred

- $W = -\Delta U$ $\{Q = 0$, as the process is adiabatic$\}$ ✓
- If W is positive, ΔU is negative, so internal energy decreases ✓
- Internal energy is indicated by temperature, so temperature decreases ✓

0 3 . 2 In practice the cut-off point **C** can be altered without changing points **A**, **B** and **E**. **Figure 5** 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 5



Compare **Figures 4** and **5** 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 marks]

Rate of Consumption of Air

- Air enters from A to C on figure 4, but A to X on figure 5
- Area under this region doubles, so energy (and therefore input power) doubles
- Air consumption is approximately doubled

Output Torque and Power

- Area is bigger by approximately 25% in figure 5, so output power is also ~25% higher
- Average pressure is higher in figure 5, so larger torque

Power = Force × Velocity ($P = Fv$)

Power = Torque × Angular Velocity ($P = T\omega$)

- Torque is proportional to power, so increase in output power is also caused by torque increase

Efficiency

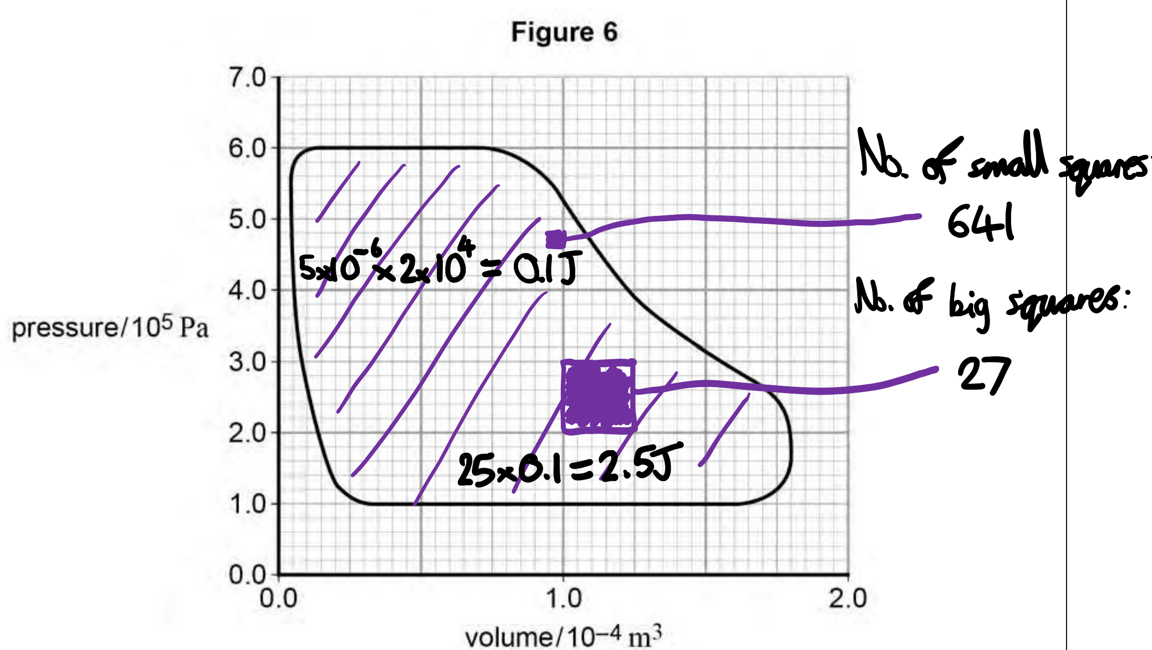
- $\text{Efficiency} = \dfrac{\text{Useful Output Power}}{\text{Total Input Power}}$
- $\dfrac{1.25 \times P_{out}}{2 \times P_{in}} = \dfrac{1.25}{2} \times \dfrac{P_{out}}{P_{in}} = \dfrac{1.25}{2} \times \text{Efficiency}$

$\dfrac{1.25}{2} < 1$ so efficiency decreases

QWC ✓

Figure 6 shows the actual indicator diagram for the air motor.

Figure 6



0 3 . 3 The motor was running at 20 cycles per second when the indicator diagram was recorded.

Determine the indicated power of the motor.

[4 marks]

- Work done shown by area of indicator diagram ✓
- 27 large squares counted ✓
- $27\times2.5=67.5$J ✓
- $67.5\text{J}\times20\text{s}^{-1}=1350$W ✓

power = 1350 W

0 3 . 4 Explain why the indicated power for the air motor is different from the output power.

[1 mark]

Friction occurs in the bearings, and between the cylinder and piston, and this is not accounted for in the indicated power. ✓

0 4 A company claims to be able to provide a combined heat and power plant for a market garden that requires both electrical power and space heating for greenhouses. The engine-driven generator will operate between temperatures of 1450 K and 310 K.

0 4 . 1 Show that the maximum theoretical efficiency of any heat engine operating between temperatures of 1450 K and 310 K is about 80%.

[1 mark]

$$\text{Max. theoretical efficiency} = \frac{T_H - T_C}{T_H}$$

T_H = temperature of source
T_C = temperature of sink

$$\frac{1450 - 310}{1450} = \frac{1140}{1450} = 0.79 = 79\%$$
$$\simeq 80\%$$

0 4 . 2 The company makes the following two claims about the performance of the plant:

- **Claim 1** When consuming biogas of calorific value 55.5 $\mathrm{MJ\ m^{-3}}$ at the rate of $5.00 \times 10^{-3}\ \mathrm{m^3\ s^{-1}}$, the electrical power output will be 210 kW.
- **Claim 2** At the same time the engine will provide heating for greenhouses at the rate of at least 55.0 kW.

Discuss the extent to which the company's claims are justified.

[5 marks]

Claim 1

- $55.5\,\mathrm{MJm^{-3}} \times 5.00\times10^{-3}\,\mathrm{m^3s^{-1}} = 0.278\,\mathrm{MJm^{-3}m^3s^{-1}}$
  $= 0.278\,\mathrm{MJs^{-1}} = 278\,\mathrm{kW}$ ✓
- $\frac{210}{278} = 0.76 = 76\%$ ✓
- Suggested efficiency is too close to the maximum theoretical efficiency, so the claim isn't justified. ✓

(Claim would be justified if the engine runs at maximum efficiency) ✓

Claim 2

- $278 - 210 = 68\,\mathrm{kW}$ ✓
- $55\,\mathrm{kW} < 68\,\mathrm{kW}$, so it is possible for 55kW to be available for heating ✓

(Efficiency of less than 79% will give more than 68kW, so 55kW is possible) ✓

END OF QUESTIONS

There are no questions printed on this page

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