AQA

Please write clearly in block capitals.

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

Surname _____

Forename(s) _____

Candidate signature _____

A-level
PHYSICS

Paper 3
Section B   Engineering physics

Thursday 14 June 2018   Morning   Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

Materials
For this paper you must have:
• a pencil and a ruler
• a scientific calculator
• a Data and Formulae Booklet.

Instructions
• Use black ink or black ball-point pen.
• Fill in the boxes at the top of this page.
• Answer **all** questions.
• You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
• Do all rough work in this book. Cross through any work you do not want to be marked.
• Show all your working.

Information
• The marks for questions are shown in brackets.
• The maximum mark for this paper is 35.
• You are expected to use a scientific calculator where appropriate.
• A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
TOTAL	

Section B

Answer **all** questions in this section.

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

[1 mark]

Conservation of linear momentum: The total linear momentum of a system remains constant if no external forces are acting
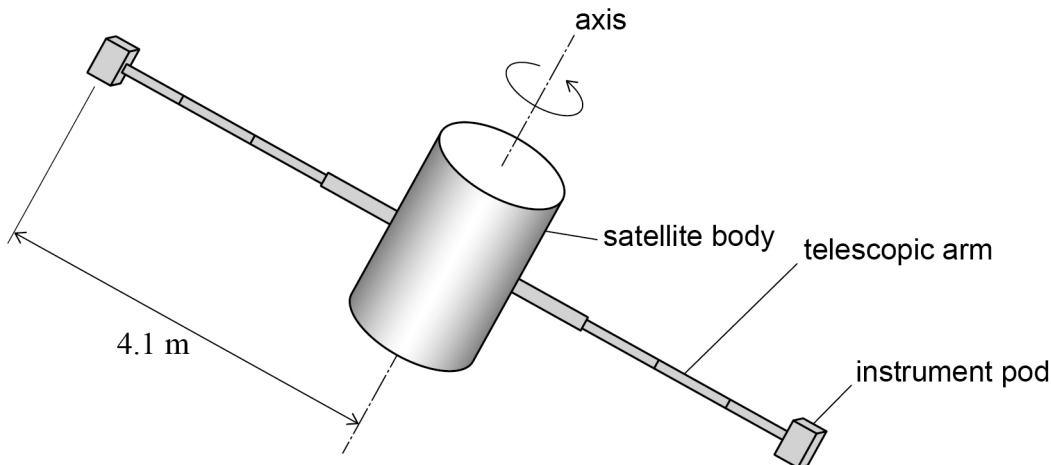
The total angular momentum of a system remains constant if there is no external torque acting ✓

0 1 . 2 **Figure 1** shows an orbiting satellite fitted with two small instrument pods attached to the ends of telescopic arms. The arms can be extended or retracted by a motor in the body of the satellite.

Figure 1

axis

satellite body   telescopic arm

instrument pod

4.1 m

With the telescopic arms fully extended, the centre of mass of each instrument pod is at a radius of 4.1 m from the axis of rotation.

moment of inertia of satellite body about axis = 71 kg m^2
mass of each instrument pod = 5.0 kg

The mass of the telescopic arms is negligible.

Show that the total moment of inertia of the satellite with the arms fully extended is 240 kg m^2

[2 marks]

moment of inertia of body

mass of pod

radius of pod

$$I = I_{body} + 2mr^2$$

total moment of inertia

moment of inertia of both pods

$$I = 71 + (2 \times 5.0 \times 4.1^2) = 239 \, kgm^2$$

$$\simeq 240 \, kgm^2$$

Question 1 continues on the next page

Turn over ▶

0 1 . 3 The satellite is initially rotating slowly about its axis with the arms fully extended. The arms are slowly retracted so that the instrument pods move closer to the body of the satellite.

State and explain the change in the angular speed of the satellite as the arms are retracted.

[3 marks]

$I = I_{body} + 2mr^2$ r decreases, so I decreases

· Total moment of inertia decreases ✓
· This is because the radius of the pods from the central axis decreases, so more of the mass is closer to the centre ✓
                                                    ⌐moment of inertia
angular momentum $= I\omega$ ⌐angular velocity
· The angular momentum remains constant, so decreasing the moment of inertia will increase the angular velocity ✓

0 1 . 4 The satellite is initially rotating at 1.3 rad s^{-1} with the telescopic arms fully extended. When fully retracted the instrument pods are at a radius of 0.74 m from the axis. The satellite contains sensitive equipment that may be damaged if the rotational speed exceeds 4.2 rad s^{-1}

Deduce whether the arms can be retracted fully without the satellite exceeding its maximum permitted angular speed.

⌐moment of inertia   **[3 marks]**
                    ⌐angular velocity
$$I_1\omega_1 = I_2\omega_2$$
                    1: before
                    2: after

$I_1 = 240 \text{ kgm}^2$
$\omega_1 = 1.3 \text{ rad s}^{-1}$ ⟶ $I_1\omega_1 = 240 \times 1.3 = 312 \text{ Nms}$ ✓
                                ⌐I_{body} ⌐radius
$$312 = I_2\omega_2 = (71 + (2 \times 5.0 \times 0.74^2))\omega_2$$
$$\omega_2 = \frac{312}{71 + (2 \times 5.0 \times 0.74^2)} = 4.08 \text{ rad s}^{-1} ✓$$

9

The arms can be retracted safely, as the final angular speed is within the limit. ✓

0 2 . 1 State **one** function of a flywheel.

or torque/power

[1 mark]

To smooth out rotational speed ✓

To store rotational kinetic energy

Question 2 continues on the next page

Turn over ▶

0 2 . 2 A student does an experiment to determine the frictional torque acting at the bearings of a steel flywheel. The flywheel has a radius of 0.075 m and is perfectly balanced.

The student places a small magnet of mass 0.020 kg at point **A** on the circumference of the flywheel on a horizontal line through the axis of rotation as shown in **Figure 2a**. The student releases the flywheel. The flywheel first comes to rest when it has moved through an angle of 3.00 rad ($172°$), with the magnet now in position **B** as shown in **Figure 2b**.

Figure 2a   **Figure 2b**

0.075 m

A

horizontal axle

frictional torque acts through 172°

$8°$

0.075m

B

$\sin(8°) = \dfrac{\Delta h}{0.075\text{m}}$
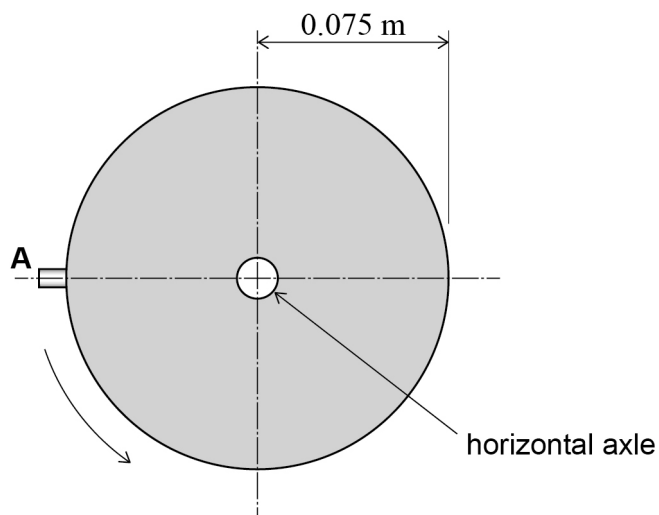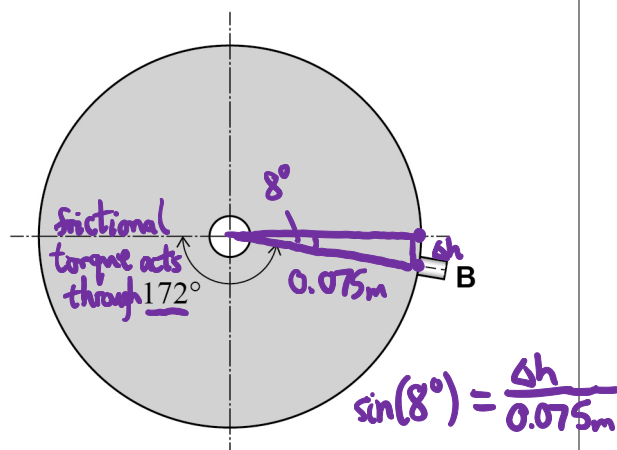
The loss in gravitational potential energy of the magnet equals the work done against the frictional torque acting at the bearings.

Show that the frictional torque is about 7×10^{-4} N m

[3 marks]

$$\Delta h = 0.075 \sin(8°) = 1.04 \times 10^{-2}\,\text{m} \checkmark$$

$$\Delta GPE = \underset{\text{mass of magnet}}{mg}\Delta h = 0.020 \times \underset{\text{gravitational field strength}}{9.81} \times 1.04 \times 10^{-2} = 2.04 \times 10^{-3}\,\text{J} \checkmark$$

$$\underset{\text{torque}}{T}\underset{\text{angle}}{\theta} = 2.04 \times 10^{-3}\,\text{J}$$

$$T = \frac{2.04 \times 10^{-3}}{3.00} = 6.80 \times 10^{-4}\,\text{Nm} \checkmark$$

0 2 . 3 The student goes on to determine the moment of inertia of the flywheel.

The magnet is removed and the flywheel is made to spin. Measurements show that the flywheel makes 573 rotations as its angular speed reduces uniformly from 25.0 rad s^{-1} to zero. Assume the frictional torque at the bearings is constant and the same as in question **02.2**.

Determine the moment of inertia of the flywheel about its axis of rotation.

[3 marks]

final velocity *displacement*

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

initial velocity *acceleration*

final angular velocity

initial angular velocity
angular acceleration

$$\omega_f^2 = \omega_i^2 + 2\alpha\theta \text{ — angular displacement} \checkmark$$

$$0 = 25.0^2 + (2 \times 573 \times 2\pi \times \alpha)$$ MAX 3×✓

$$\alpha = \frac{-25.0^2}{2 \times 573 \times 2\pi} = -0.087 \text{ rad.s}^{-2} \checkmark$$

moment of inertia

resultant torque

$$I = \frac{T}{\alpha} = \frac{-6.80 \times 10^{-4}}{-0.087} = 7.82 \times 10^{-3} \text{ kgm}^2 \checkmark$$

angular acceleration

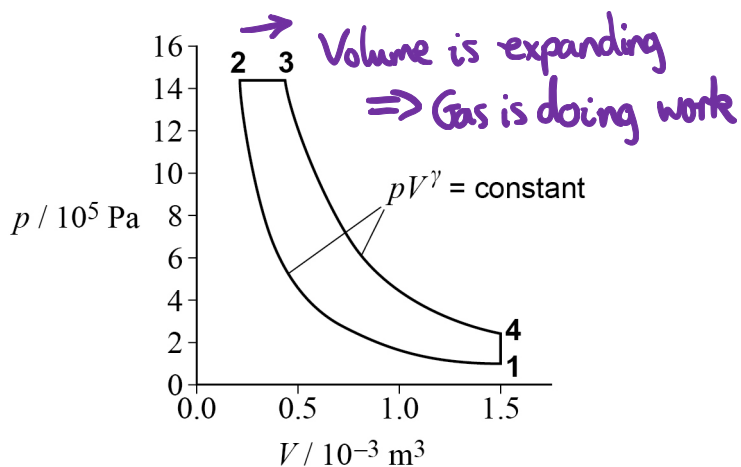moment of inertia = 7.82×10^{-3} _____ kg m^2

7

Turn over for the next question

0 3   **Figure 3** 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 3

Volume is expanding ⇒ Gas is doing work

pV^γ = constant

p / 10^5 Pa

V / 10^{-3} m^3

0 3 . 1   Which statement about this cycle is true?
Tick (✓) the correct answer.

[1 mark]

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. ☐
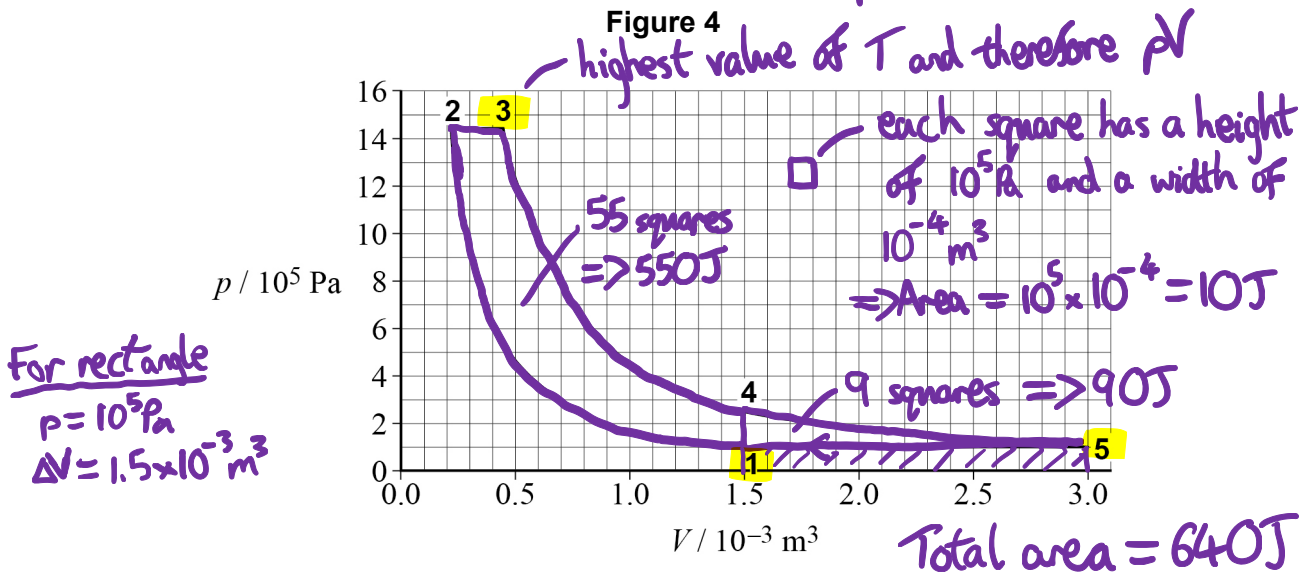
0 3 . 2   The cycle in **Figure 3** may be modified by allowing the air to continue to expand adiabatically from state **4** until it is at atmospheric pressure at state **5**.
Figure 4 shows the modified cycle.

Figure 4

$pV = nRT$

highest value of T and therefore pV

each square has a height of 10^5 Pa and a width of 10^{-4} m³

⇒ Area = $10^5 \times 10^{-4}$ = 10J

p / 10^5 Pa

55 squares ⇒ 550J

For rectangle
$p = 10^5$ Pa
$\Delta V = 1.5 \times 10^{-3}$ m³

9 squares ⇒ 90J

V / 10^{-3} m³

Total area = 640J

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 3**, the modified cycle of **Figure 4** 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.

[5 marks]

Claim **A**

- Each square represents 10J ✓
- The extension to the loop has an area of 9 squares, which corresponds to 90J ✓
- Claim is untrue ←

✓

Claim **B**

- Original efficiency = $\dfrac{550J}{input}$

- New efficiency = $\dfrac{640J}{input}$

- Change in efficiency = $\dfrac{640J}{input} - \dfrac{550J}{input} = \dfrac{90J}{input}$

- % increase in efficiency = $\dfrac{90/input}{550/input} = \dfrac{90}{550} = 0.16 = 16\%$ ✓

Claim is true ✓

Question 3 continues on the next page

0 3 . 3 The first law of thermodynamics can be written as

$$Q = \Delta U + W$$ — work done on or by the system

State the meaning of the terms Q and ΔU in this equation.

[2 marks]

Q Energy gained or lost from the system as heat ✓

ΔU Change in internal energy ✓

0 3 . 4 For the air in process **5 → 1** in **Figure 4**, $\Delta U = -374$ J

Calculate the energy that must be removed by cooling for process **5 → 1**.

[2 marks]

$$W = p\Delta V = 10^5 \times 1.5 \times 10^{-3} = 150 \text{ J} ✓$$

$$Q = \Delta U + W$$
$$= -374 - 150 = -524 \text{ J}$$

energy removed by cooling = **524 J** ✓   J

0 3 . 5   0.060 mol of air is taken through the cycle.

Determine the maximum temperature in the cycle.

[3 marks]

$pV = nRT$

- volume
- molar gas constant
- temperature in kelvin
- pressure
- number of moles

• Highest temperature is at point 3, as pV is highest ✓

$\rightarrow p = 14.5 \times 10^5 \, Pa$

$\rightarrow V = 0.45 \times 10^{-3} \, m^3$

$T = \dfrac{pV}{nR}$ ✓ $= \dfrac{14.5 \times 10^5 \times 0.45 \times 10^{-3}}{0.060 \times 8.31} = 1310K$ ✓

maximum temperature = <u>   1310   </u> K

13

Turn over for the next question

Turn over ▶

0 4 The National Grid is supplied mainly from power stations which have overall efficiencies of up to about 40%

Table 1 shows the average power requirements of a large paper-manufacturing business (a paper mill).

Table 1

Requirement	Average power / MW
for driving electric motors for wood grinders, pumps, fans, etc.	49
for heating, ie boiling and drying in the paper-making process and for heating the paper mill	141
for running electrical office equipment, lighting, etc.	8

57MW

The paper mill can either

At 60MW, 107MW can be supplied to heating, so 34MW required

• 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.

[6 marks]

Maximum Theoretical Efficiency

• All heat engines must obey the 2ⁿᵈ law of thermodynamics

→ They must give out (reject) energy to the surroundings

- Maximum theoretical efficiency $= \dfrac{T_H - T_c}{T_H}$ — temperature of cold region ↓ (in K) ↑ temperature of hot region

- For 100% efficiency, $T_H - T_c = T_H$
  i.e. $T_c = 0K$

- Friction and incomplete combustion would result in unwanted energy losses

Analysis of Data

- 60MW would cover the electrical requirements but not the heating requirements

- 57MW (useful) needed for the electrical requirements, so at 36% efficiency the input would need to be $\dfrac{57}{0.36} = 158MW$

- $158 - 57 = 101MW$, which is not enough to meet the heating requirements

- At least 34MW must come from the National Grid

- If all power comes from the National Grid, 198MW corresponds to a total input of $\dfrac{198}{0.4} = 495MW$

Question 4 continues on the next page

6

Turn over ▶

·The advantage of the CHP system is that energy which is otherwise wasted would be utilised.

Conclusion [→ This makes it preferable to taking energy directly from the National Grid.]

END OF QUESTIONS

There are no questions printed on this page

**DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED**

There are no questions printed on this page

There are no questions printed on this page

**DO NOT WRITE ON THIS PAGE
ANSWER IN THE SPACES PROVIDED**