AQA

Please write clearly in block capitals.

Centre number: 9 3 7 5 1

Candidate number: 0 5 8 2

Surname: Matheson

Forename(s): Lewis

Candidate signature: [signature]

I declare this is my own work.

A-level PHYSICS

Paper 3
Section B Engineering physics

ALevelPhysicsOnline.com

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
- a protractor.

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.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- 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	

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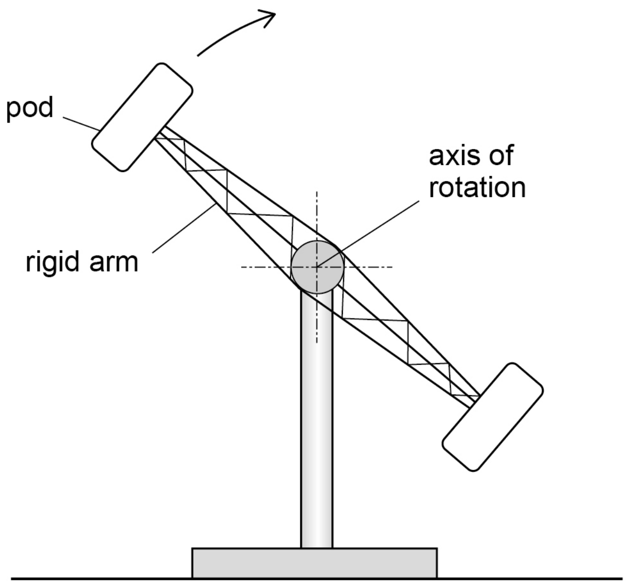
Section B

Answer **all** questions in this section.

0 1 **Figure 1** shows a fairground ride.

Figure 1



The ride consists of a rotor that rotates in a vertical circle about a horizontal axis.
The rotor has two rigid arms. A pod containing passengers is attached to each arm.
The rotor is perfectly balanced.
The direction of rotation of the rotor is reversed at times during the ride.

Question 1 continues on the next page

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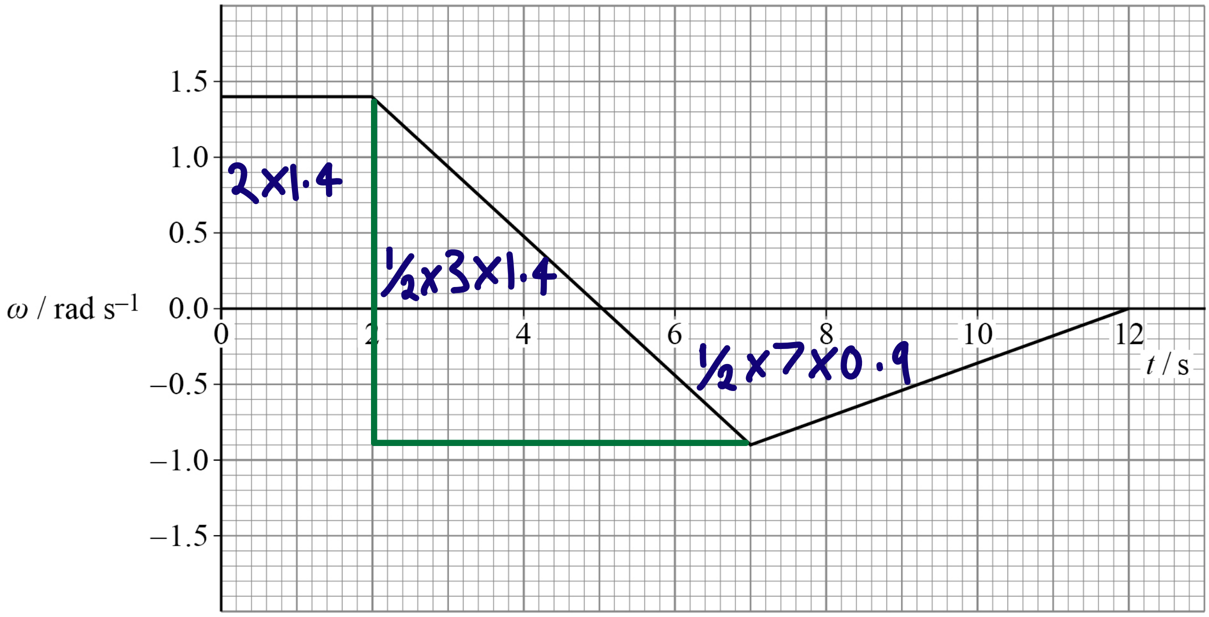
Figure 2 shows the variation of the angular velocity ω of the rotor with time t during a 12 s period.

Figure 2



0 1 . 1 Determine the mean angular velocity of the rotor during the 12 s period.

[2 marks]

$\omega = \frac{\theta}{t}$ θ = area = 2.8 + 2.1 − 3.15 ✓

θ = 1.75 rad

$\omega = \frac{1.75}{12} = 0.146$

mean angular velocity = 0.15 ✓ rad s^{-1}

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The moment of inertia of the rotor about its axis of rotation is 2.1×10^4 kg m^2.
A constant frictional torque of 390 N m acts at the bearings of the rotor.

0 1 . 2 Calculate the power output of the driving mechanism during the first 2 s shown in **Figure 2**.

[1 mark]

$P = T\omega = 390 \times 1.4$ ← ω for first 2 s

$= 546$

power output = 546 ✓ W

0 1 . 3 Calculate the maximum torque applied by the driving mechanism to the rotor during the 12 s period.

[3 marks]

$T = I\alpha_{max}$

α_{max} = gradient of graph at steepest point

$\frac{\Delta y}{\Delta x} = \frac{-0.9-1.4}{7.0-2.0} = -0.46$ rad s^{-2} ✓

$T = I\alpha = 2.1 \times 10^4 \times 0.46 = 9660$ ✓

$T_{total} = 9660 + 390 = 10\,050$

maximum torque = 1.0×10^4 ✓ N m

0 1 . 4 Calculate the magnitude of the angular impulse on the rotor between $t = 2.0$ s and $t = 7.0$ s.

[1 mark]

Angular impulse $= T \times t = 9660 \times (7.0 - 2.0)$

$= 48\,300$

angular impulse = 4.8×10^4 ✓ N m s

Question 1 continues on the next page

Turn over ►

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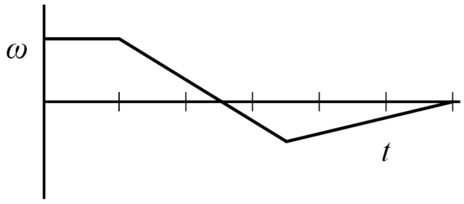
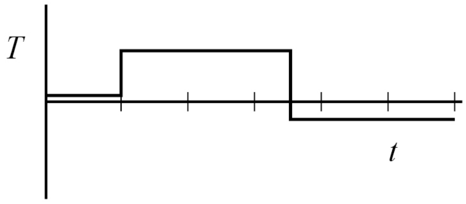
0 1 . 5 Which graph best shows the variation of the torque T applied to the rotor for the $12\ \text{s}$ period?
Tick (✓) **one** box.

A copy of **Figure 2** is provided to help you.

[1 mark]



copy of **Figure 2**



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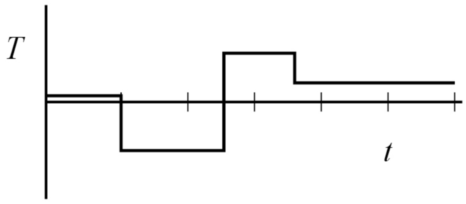

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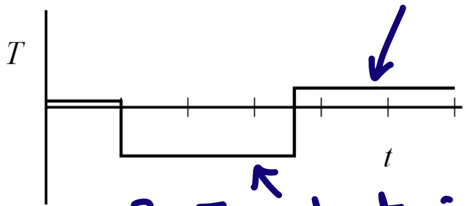
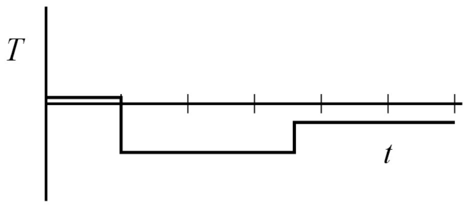
7-12 gradient is positive



☑ ✓

2-7 gradient is negative



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0 2 A moving tram is powered by energy stored in a rapidly spinning flywheel.

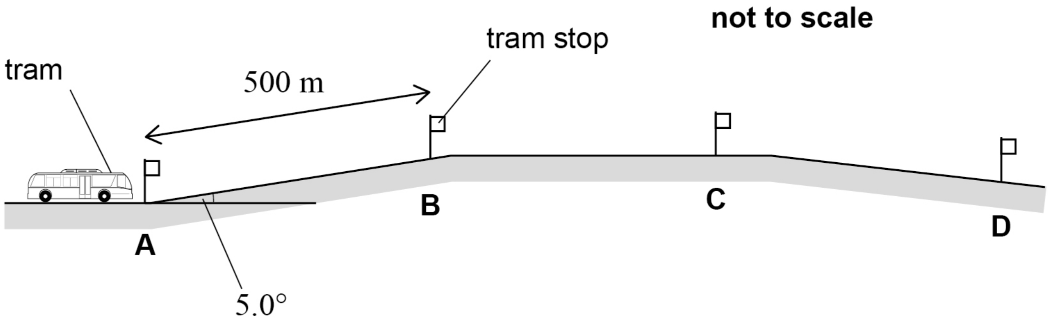
When the tram is at a tram stop, the flywheel is 'charged' by being accelerated to a high rotational speed.

The mass of the tram, flywheel and passengers is 1.46×10^4 kg.

The distance between tram stops is 500 m.

Figure 3 shows that between stops **A** and **B** the track is inclined at a constant 5.0° to the horizontal.

Figure 3



The tram must travel 500 m along this incline on one charge of energy.

The total resistive force on the tram due to its motion is constant at 1.18 kN.

The flywheel is a solid steel disc of diameter 1.00 m. It has a moment of inertia of 62.5 kg m^2.

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0 2 . 1 Calculate the minimum angular speed of the flywheel when the tram leaves stop **A** so that the tram reaches stop **B** using only energy stored in the flywheel.

[3 marks]

$E_{flywheel} = \frac{1}{2} I \omega^2$

$E_{required} = E_p + W_{Friction} = mgh + Fs$

$E = (1.46 \times 10^4 \times 9.81 \times 500 \sin 5.0) + (1.18 \times 10^3 \times 500)$

$E = 6.24 \times 10^6 + 5.9 \times 10^5$ ✓ ← 2sf

$\omega = \sqrt{\frac{2E}{I}} = \sqrt{\frac{2 \times (6.24 \times 10^6 + 5.9 \times 10^5)}{62.5}} = 467.55$

minimum angular speed = 4.7×10^2 ✓ rad s^{-1}

↑ 2sf

0 2 . 2 Between stops **C** and **D** the tram travels downhill.

Suggest **two** advantages of keeping the flywheel connected to the driving wheels when the tram travels downhill.

[2 marks]

1 Flywheel can be used as a brake, as E_p change transferred to E_K of flywheel ∴ less energy transferred to the brakes. ✓

2 Flywheel can store energy that can later be used to accelerate the tram. ✓

Question 2 continues on the next page

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0 2 . 3 The same tram is to be used on a track where the stops are further apart, so the flywheel system needs to be modified.

Discuss the design features of the flywheel that will enable it to store more energy without increasing the mass of the tram.

In your answer you should consider:

- the design of the flywheel
- how the choice of materials used to make the flywheel is influenced by its design and maximum angular speed
- other design aspects that allow for high angular speeds of the flywheel.

[6 marks]

$E_K = \frac{1}{2} I \omega^2$ and $I = \Sigma mr^2$

Design: Arrange more of the mass at outer edge of flywheel to increase moment of inertia. This could be achieved with a heavy rim and thin spokes (like a bicycle wheel) and having a large radius. ✓✓

Material: High density material with high tensile strength e.g. titanium ✓✓

High angular speed: Reduce friction as much as possible by using lubrication, have smooth surfaces and encase within a vacuum. ✓✓

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Turn over for the next question

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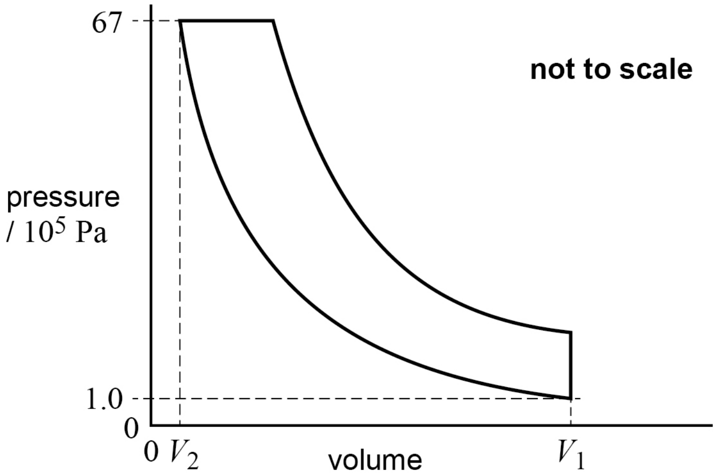
0 3 . 1 Explain what is meant by an adiabatic change.

[1 mark]

A change where there is no energy transfer to or from a system. ✓

0 3 . 2 **Figure 4** shows the p–V diagram for an ideal diesel engine cycle.

Figure 4



In this cycle, air is compressed adiabatically from a pressure of 1.0×10^5 Pa and volume V_1 to a pressure of 67×10^5 Pa and volume V_2.
The adiabatic index γ for air $= 1.4$

Calculate the compression ratio $\frac{V_1}{V_2}$.

[2 marks]

$$p_1 V_1^{\gamma} = p_2 V_2^{\gamma}$$

$$\frac{p_2}{p_1} = \frac{V_1^{\gamma}}{V_2^{\gamma}} = \left(\frac{V_1}{V_2}\right)^{\gamma}$$

$$\frac{V_1}{V_2} = \sqrt[\gamma]{\frac{p_2}{p_1}}$$

$$\frac{V_1}{V_2} = \sqrt[1.4]{\frac{67 \times 10^5}{1.0 \times 10^5}} = 20.153$$

compression ratio = 20

Question 3 continues on the next page

0 3 . 3 Explain why the compression ratio for a diesel engine must be greater than the compression ratio for a petrol engine.

[2 marks]

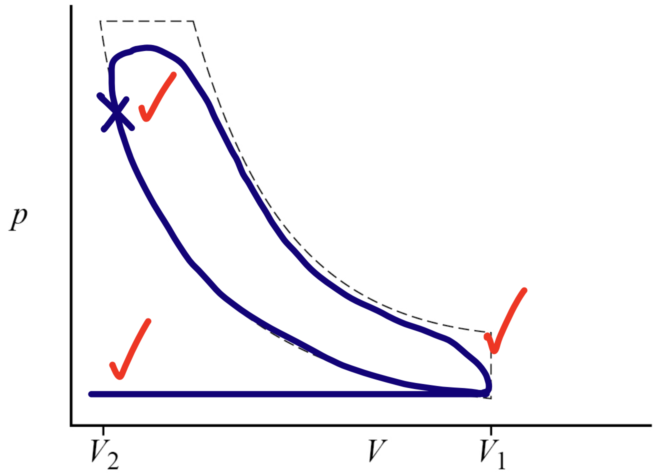
Diesel requires a high compression ratio to give a temperature high enough to ignite the fuel. ✓ The petrol vapour-air mixture is ignited at a lower temperature with a spark plug. ✓

The dashed lines in **Figure 5** show the p–V diagram for the ideal diesel engine cycle.

0 3 . 4 Draw, on **Figure 5**, a typical indicator diagram for a real four-stroke diesel engine with the same values of V_1 and V_2.

[2 marks]

Figure 5



0 3 . 5 Mark with an **X** on your diagram the point where the injection of fuel starts.

[1 mark]

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0 3 . 6 Explain **two** differences between the ideal cycle and the indicator diagram for the real engine.

[2 marks]

1 Corners are curved because valves take a finite time to open and close. ✓

2 Energy lost by heat transfer ∴ compression and expansion curves are not adiabatic. ✓

10

Turn over for the next question

0 4 **Figure 6** shows a low-voltage solid-state thermoelectric cooling element.
The element is a square of side 40 mm and is 4 mm thick.

Figure 6

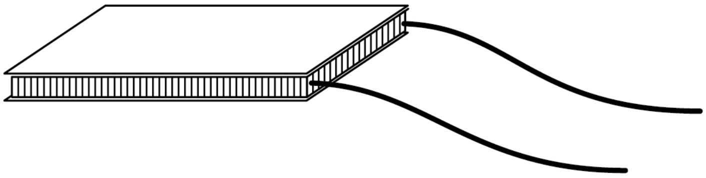
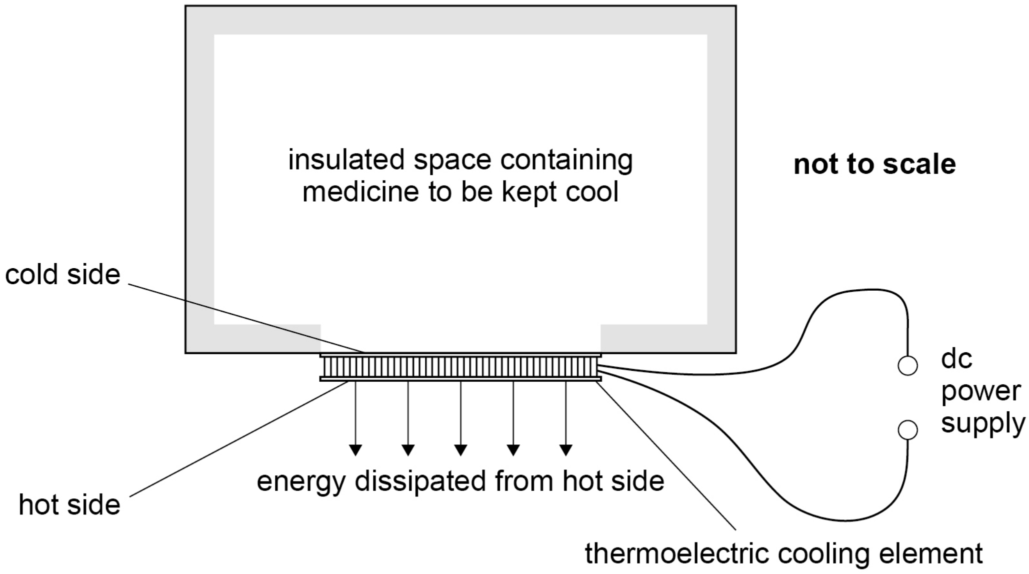


Figure 7 shows how the element is used as part of a thermoelectric refrigerator to keep small quantities of medicine at a low temperature.

Figure 7



The manufacturer's data for the element show that when the temperature of the hot side is 35 °C and the temperature of the cold side is 5 °C:

- the rate at which energy is dissipated from the hot side is 65 W Q_H
- the electrical power supplied is 28 W. W

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0 4 . 1 It is claimed that the coefficient of performance (COP) of a thermoelectric refrigerator is much less than the COP of an ideal refrigerator.

Discuss whether the claim is valid for the thermoelectric refrigerator in this question.

[4 marks]

Ideal : $COP = \frac{T_c}{T_H - T_c} = \frac{273+5}{(273+35)-(273+5)}$

$= 9.27$ ✓

Real : $COP = \frac{Q_c}{W} = \frac{Q_H - W}{W}$ ✓ $= \frac{65-28}{28}$

$= 1.32$ ✓

Actual COP much lower than ideal therefore claim is valid. ✓

0 4 . 2 Suggest why a small value of the COP might be acceptable for this particular application of a thermoelectric cooling element.

[2 marks]

The thermoelectric cooler is small and portable and requires low maintenance ✓ which outweighs the poor COP. ✓

6

END OF QUESTIONS

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