

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3

Section B Engineering physics

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.

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.

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



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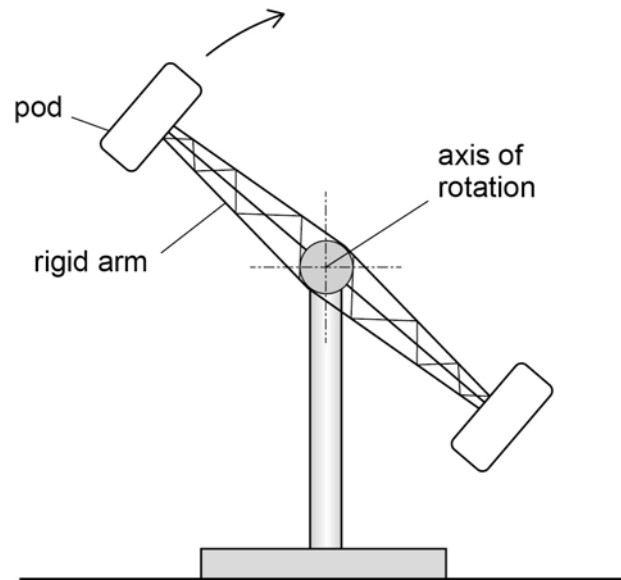
Section B

Answer **all** questions in this section.

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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.

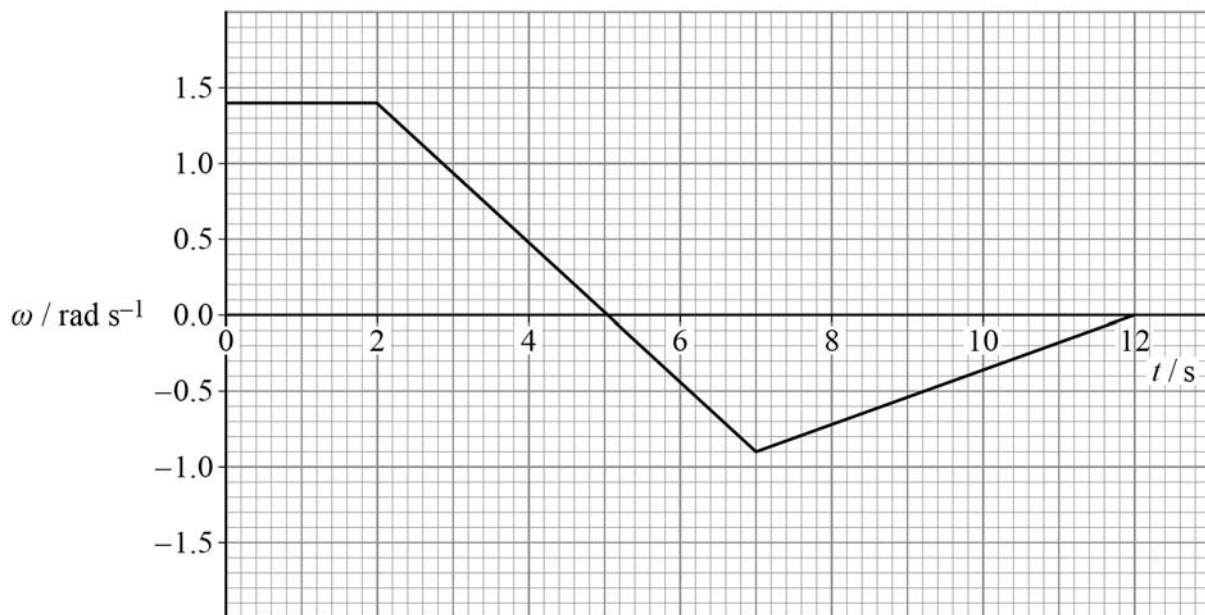
Question 1 continues on the next page

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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]

Angular displacement = area under ω - t graph

$$= (2.0 \times 1.40) + \left(\frac{1}{2} \times 3.0 \times 1.40\right) - \left(\frac{1}{2} \times 7.0 \times 0.90\right)$$

$$= 2.80 + 2.10 - 3.15 = 1.75 \text{ rad}$$

$$\text{mean } \omega = 1.75 \div 12.0 = 0.146 \text{ rad s}^{-1}$$

mean angular velocity = 0.15 rad s⁻¹



The moment of inertia of the rotor about its axis of rotation is $2.1 \times 10^4 \text{ kg m}^2$.
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]

Driving torque = frictional torque (ω constant)

$$P = T\omega = 390 \times 1.40 = 546 \text{ W}$$

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]

Steepest part of graph: $t = 2.0 \text{ s}$ to 7.0 s

$$\alpha = \Delta\omega/\Delta t = (1.40 - (-0.90)) \div 5.0 = 0.46 \text{ rad s}^{-2}$$

$$T = I\alpha = 2.1 \times 10^4 \times 0.46 = 9660 \text{ N m}$$

$$\text{Add frictional torque: } 9660 + 390 = 10\,050 \text{ N m}$$

maximum torque = 1.01×10^4 N m

0 1 . 4

Calculate the magnitude of the angular impulse on the rotor between $t = 2.0 \text{ s}$ and $t = 7.0 \text{ s}$.

[1 mark]

$$\text{Angular impulse} = \Delta(I\omega) = 2.1 \times 10^4 \times (1.40 - (-0.90))$$

$$= 2.1 \times 10^4 \times 2.30 = 4.8 \times 10^4 \text{ N m s}$$

angular impulse = 4.8×10^4 N m s

Question 1 continues on the next page

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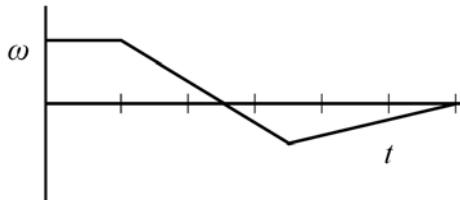
0 1 . 5

Which graph best shows the variation of the torque T applied to the rotor for the 12 s period?

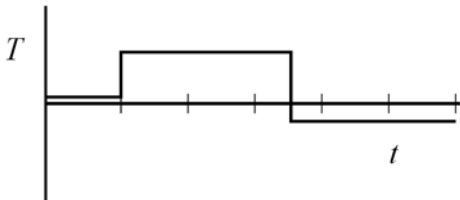
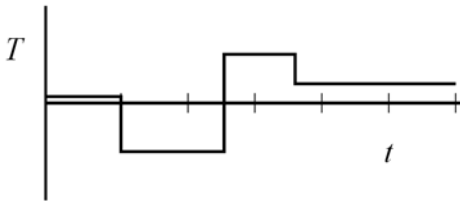
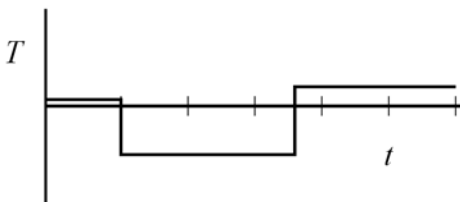
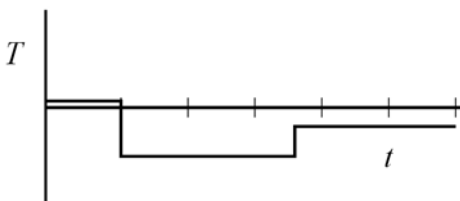
Tick (✓) **one** box.

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

[1 mark]



copy of **Figure 2**


☐

☐

☒

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0 2

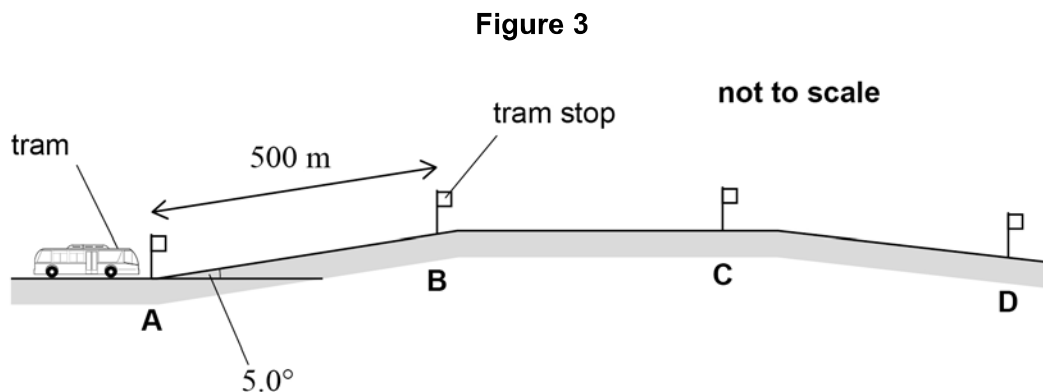
A moving tram is powered by energy stored in a rapidly spinning flywheel.

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.



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 .



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]

$$\text{Work done against gravity} = mgh, \text{ with } h = 500 \sin 5.0^\circ$$

$$= 1.46 \times 10^4 \times 9.81 \times 500 \times \sin 5.0^\circ = 6.24 \times 10^6 \text{ J}$$

$$\text{Work done against resistance} = F \times s = 1.18 \times 10^3 \times 500$$

$$= 5.9 \times 10^5 \text{ J}$$

$$\text{Work done by flywheel} = 6.24 \times 10^6 + 5.9 \times 10^5 = 6.83 \times 10^6 \text{ J}$$

$$\frac{1}{2}I\omega^2 = 6.83 \times 10^6 \text{ J}$$

$$\omega = \sqrt{(2 \times 6.83 \times 10^6 \div 62.5)} = 468 \text{ rad s}^{-1}$$

minimum angular speed = 468 rad s⁻¹

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 The flywheel acts as a brake; the loss of gravitational potential energy of the tram is converted to kinetic energy of the flywheel, so less energy is wasted in the brakes and the tram does not reach too high a speed.

2 The flywheel is charged (stores energy) going downhill, so this energy can be reused for later acceleration and driving, and less recharging energy is needed at the next stop.

Question 2 continues on the next page

Turn over ►



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]

Energy stored $E_k = \frac{1}{2}I\omega^2$, so to store more energy without increasing the mass of the tram (or flywheel), the moment of inertia I and/or the maximum angular speed ω must be increased. Increasing ω is most effective since $E_k \propto \omega^2$, so a small increase in ω gives a large increase in E_k .

Design (shape): $I = \Sigma mr^2$, so I depends on the mass and how it is distributed about the axis. For the same mass, more of the mass should be arranged at the outer edge, e.g. a heavy rim joined to the axle by spokes or a thin central web, instead of a solid disc. The radius could also be increased so that the mass is further from the axis.

Materials: the rim should be made of a higher density material so that more mass is concentrated at large radius. At high angular speeds there are very large rotational (centripetal) stresses, so the material must have a high tensile (breaking) strength so the flywheel does not burst, e.g. a titanium alloy or carbon-fibre reinforced polymer (CFRP). A stronger material allows a higher maximum ω .

Other aspects for high ω : reduce the frictional torque at the bearings by using lubrication, roller bearings, air bearings or magnetic bearings.

Enclose the flywheel in a vacuum casing and give it smooth outer surfaces to reduce air resistance. The flywheel must be perfectly



balanced to prevent vibration at high speed, and gyroscopic effects must be allowed for when the tram turns, e.g. by mounting it in gimbals or using two counter-rotating flywheels.

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03.1

Explain what is meant by an adiabatic change.

[1 mark]

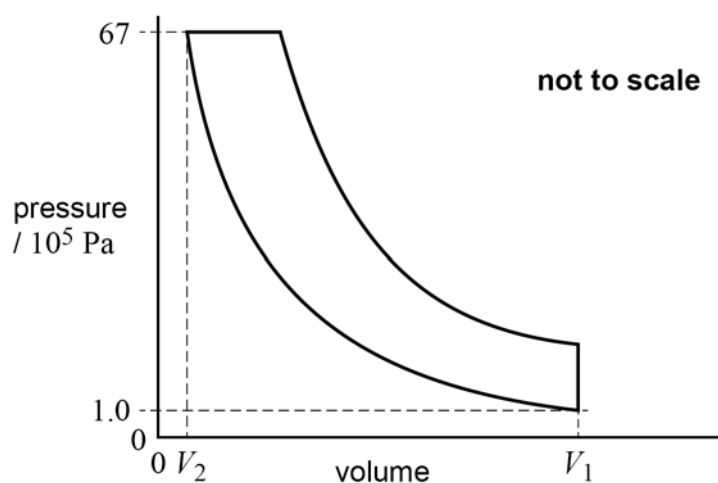
A change in which there is no heat (energy) transfer to or from the gas (system), i.e. $Q = 0$.



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]

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

$$1.0 \times 10^5 \times V_1^{1.4} = 67 \times 10^5 \times V_2^{1.4}$$

$$(V_1 / V_2)^{1.4} = 67, \text{ so } V_1 / V_2 = 67^{(1/\gamma)}$$

$$V_1 / V_2 = 20.2$$

compression ratio = 20.2 (20 : 1)

Question 3 continues on the next page

Turn over ►



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]

A diesel engine has no spark plug: the fuel self-ignites when it is injected, so a high compression ratio is needed to make the temperature of the air high enough to ignite the fuel.

In a petrol engine the petrol vapour and air mixture is ignited by a spark, so it works at lower pressures and temperatures (a high ratio would cause pre-ignition).

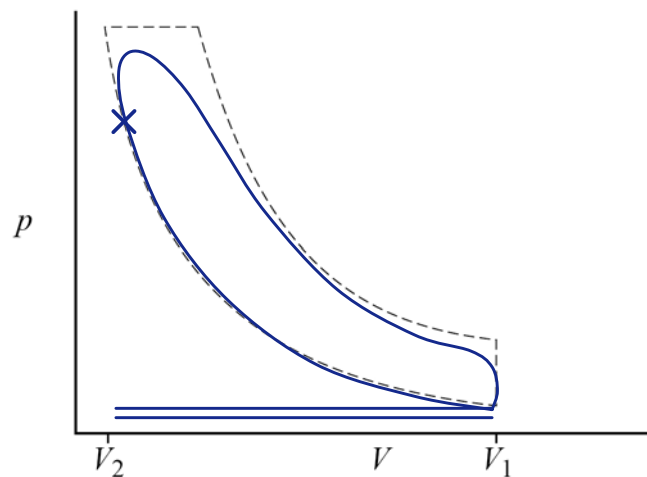
The dashed lines in **Figure 5** show the p - V diagram for the ideal diesel engine cycle.

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]



0 3 . 6

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

[2 marks]

1 *The corners are rounded, not sharp, because the valves take a finite time to open and close.*

2 *Heat input is not at constant pressure (no flat top), because fuel injection and combustion cannot be exactly controlled.*

10

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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

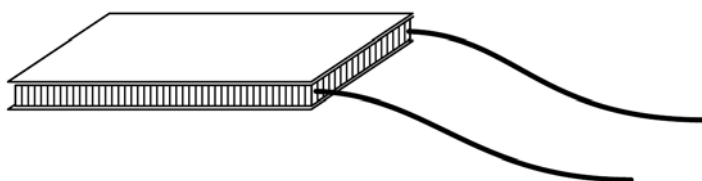
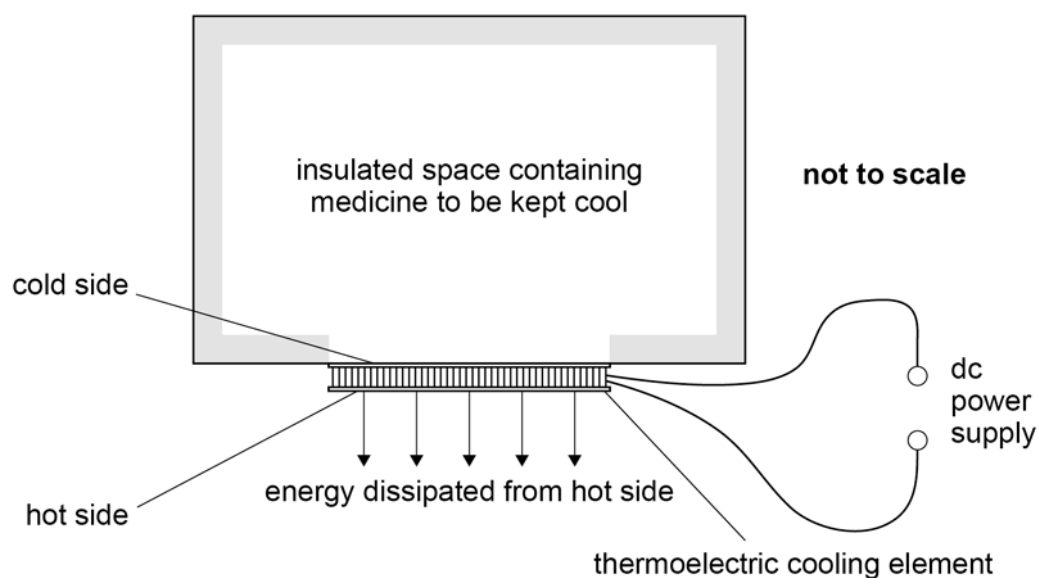


Figure 7 shows how the element is used as part of a thermoelectric refrigerator to keep small quantities of medicine at a low temperature.

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
- the electrical power supplied is 28 W.



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]

$$Q_C = Q_H - W = 65 - 28 = 37 \text{ W}$$

$$\text{Actual } COP_{\text{ref}} = Q_C \div W = 37 \div 28 = 1.32$$

$$T_H = 35 + 273 = 308 \text{ K}, \quad T_C = 5 + 273 = 278 \text{ K}$$

$$\text{Ideal } COP_{\text{ref}} = T_C \div (T_H - T_C) = 278 \div (308 - 278) = 9.3$$

*The actual COP (1.32) is very low compared with the ideal COP (9.3),
about 7 times smaller, so the 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 element is small, simple and highly portable, with no moving parts

and no fluids to leak, so it needs little maintenance and can run from

batteries or a solar panel (e.g. carrying medicine in hot countries).

Its power consumption is low (28 W), so this convenience outweighs

the poor COP: the waste of electrical energy is acceptable, and the COP

is still above 1, so the cooling power is more than the power supplied.

6

END OF QUESTIONS



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