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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

Tuesday 17 June 2025

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
- 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

The rotating part of an electric motor is called the rotor.

Figure 1 shows an end view of a rotor turning clockwise due to a driving torque from the motor. In this question, the clockwise direction is treated as positive.

Figure 1

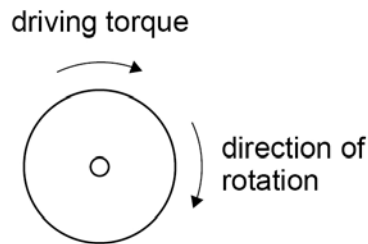
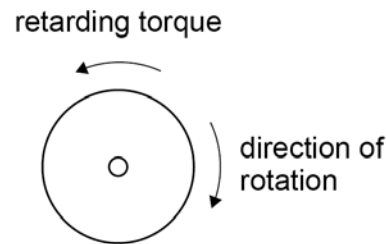


Figure 2



The rotor can be brought to rest rapidly by reversing the electrical supply connections to the motor. **Figure 2** shows the rotor at time $t = 0$ when the supply connections are reversed.

The rotor then slows down due to a constant anticlockwise retarding torque so that it stops at time $t = t_1$.

The angular velocity of the rotor at $t = 0$ is 98.0 rad s^{-1} clockwise.

The applied torque on the rotor at $t = 0$ is anticlockwise.

The applied torque produces a constant angular acceleration of -303 rad s^{-2} .

Friction torque is negligible.

0 1 . 1

Determine t_1 .

[2 marks]

$$\omega_1 = \omega_0 + \alpha t_1$$

$$0 = 98.0 + (-303) \times t_1$$

$$t_1 = 98.0 \div 303 = 0.323 \text{ s}$$

$$t_1 = \underline{0.323} \text{ s}$$



The electrical supply remains connected and the rotor now accelerates uniformly anticlockwise with an acceleration of magnitude 303 rad s^{-2} .

At a later time $t = t_2$, the angular velocity of the rotor is -120 rad s^{-1} .

- 0 1 . 2** Determine the number of anticlockwise revolutions made by the rotor between t_1 and t_2 .

[2 marks]

$$\text{From } t_1 \text{ to } t_2: \omega_1 = 0, \omega_2 = -120 \text{ rad s}^{-1}, \alpha = -303 \text{ rad s}^{-2}$$

$$\omega_2^2 = \omega_1^2 + 2\alpha\theta$$

$$(-120)^2 = 0 + 2 \times (-303) \times \theta$$

$$\theta = 14\,400 \div (-606) = -23.8 \text{ rad (23.8 rad anticlockwise)}$$

$$\text{number of revolutions} = \theta \div 2\pi = 23.8 \div 2\pi = 3.78$$

$$\text{number of revolutions} = \underline{\quad 3.78 \quad}$$

- 0 1 . 3** The moment of inertia of the rotor about the axis of rotation is $9.60 \times 10^{-2} \text{ kg m}^2$.

Calculate the angular impulse on the rotor between $t = 0$ and t_2 .

[1 mark]

$$\text{Angular impulse} = \Delta(l\omega) = I(\omega_2 - \omega_0)$$

$$= 9.60 \times 10^{-2} \times (-120 - 98.0)$$

$$= -20.9 \text{ N m s}$$

$$\text{angular impulse} = \underline{\quad -21 \quad} \text{ N m s}$$

Question 1 continues on the next page

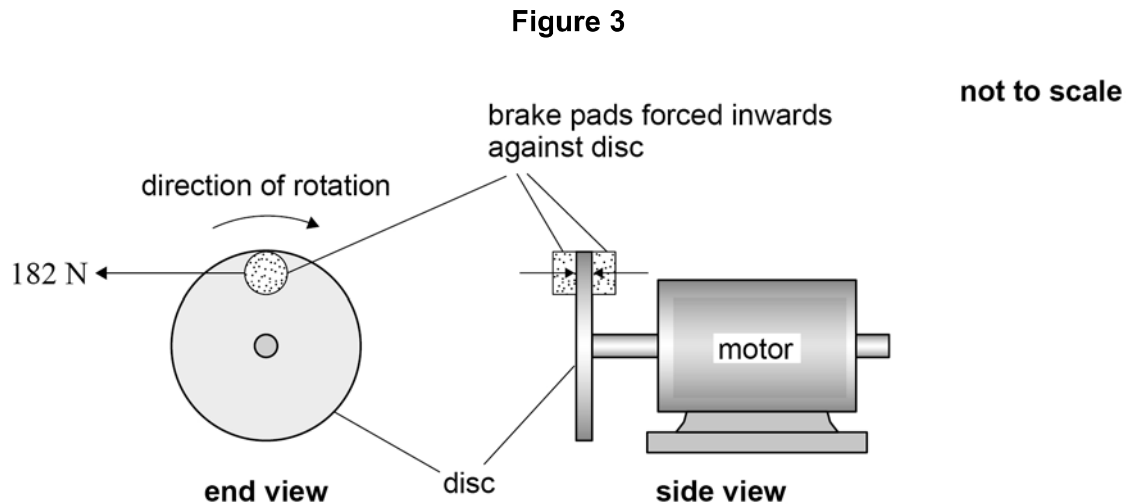
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0 1 4

Another way of quickly stopping the motor is to use a disc brake. The motor is brought to rest by switching off the power supply and then forcing two brake pads against the disc.

Figure 3 shows the two brake pads each applying a constant retarding force of 182 N to the disc.



moment of inertia of rotor and disc about the axis of rotation = 0.101 kg m^2

diameter of disc = 0.160 m

diameter of pad = 22 mm

Compare the angular deceleration produced by the disc brake system with the angular deceleration produced by reversing the electrical connections.

[3 marks]

r = distance from axis to line of action of force (centre of pad)

$$r = (0.160 \div 2) - (0.022 \div 2) = 0.080 - 0.011 = 0.069 \text{ m}$$

$$\text{Torque from two pads: } T = Fr = 2 \times 182 \times 0.069 = 25.1 \text{ N m}$$

$$\alpha = T \div I = 25.1 \div 0.101$$

$$\alpha = 249 \text{ rad s}^{-2} \text{ (deceleration)}$$

The disc brake gives an angular deceleration of 249 rad s^{-2} , which is

less than the 303 rad s^{-2} produced by reversing the connections.

So reversing the electrical connections provides the greater deceleration

and stops the rotor more quickly.



0 2 . 1

The moment of inertia I of any rolling object about its axis of rotation is given by

$$I = Amr^2$$

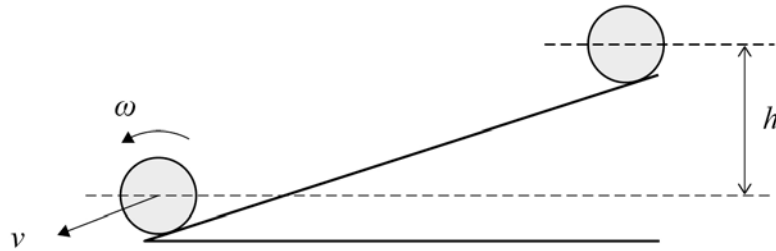
where A is a constant that depends on the shape of the object

m is the mass of the object

r is the radius of the object.

Figure 4 shows an object that starts from rest and rolls down a slope without slipping.

Figure 4



The object falls a vertical distance h . It then has a linear velocity v and angular velocity ω .

For a rolling object the linear velocity v of the centre of mass is related to the angular velocity ω by $v = r\omega$.

Show, by considering the energy transfers that occur, that

$$v = \sqrt{\frac{2gh}{1+A}}$$

[3 marks]

Loss of GPE = gain in linear E_k + gain in rotational E_k

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

Substitute $I = Amr^2$ and $\omega = v \div r$:

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}(Amr^2)(v^2 \div r^2) = \frac{1}{2}mv^2 + \frac{1}{2}Amv^2$$

$$m \text{ and } r^2 \text{ cancel: } gh = \frac{1}{2}v^2(1+A), \text{ so } 2gh = v^2(1+A)$$

$$v^2 = 2gh \div (1+A), \text{ so } v = \sqrt{2gh \div (1+A)}$$

Question 2 continues on the next page

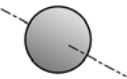
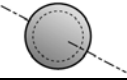
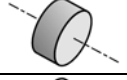
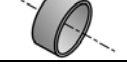
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Table 1 gives the moments of inertia of a solid sphere **P**, a hollow sphere **Q**, a solid cylinder **R** and a hollow cylinder **S** about their axes of rotation.

P, **Q**, **R** and **S** have the same mass m and outer radius r .

Table 1

Object		Moment of inertia
solid sphere P		$\frac{2}{5}mr^2$
hollow sphere Q		$\frac{2}{3}mr^2$
solid cylinder R		$\frac{1}{2}mr^2$
hollow cylinder S		mr^2

0 2 . 2

Explain why the hollow sphere **Q** has a greater moment of inertia about its axis of rotation than the solid sphere **P**.

[1 mark]

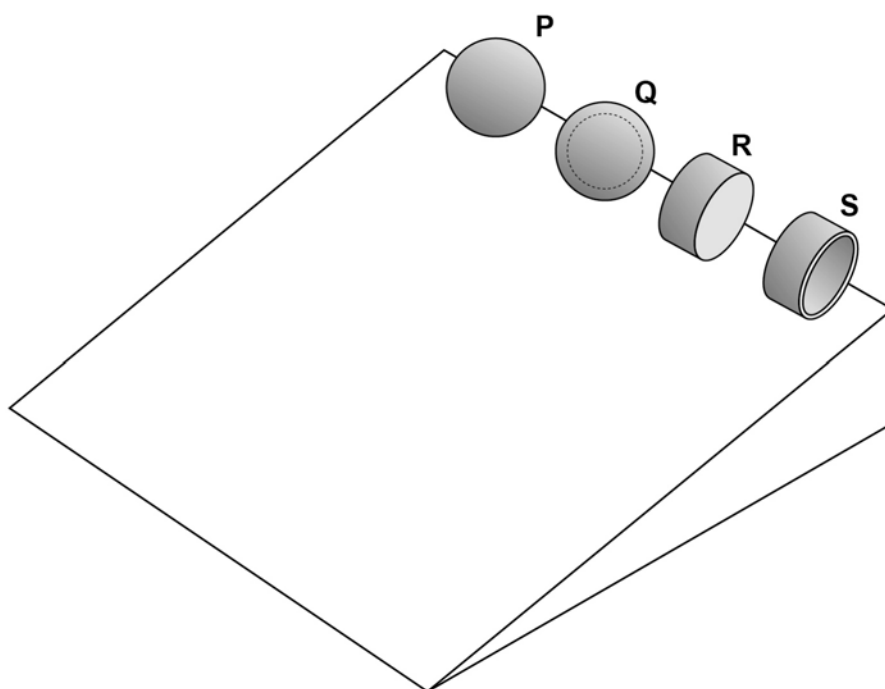
In the hollow sphere more of the mass is at a greater distance from the axis of rotation ($I = \Sigma mr^2$), so its moment of inertia is greater.



0 2 3

Figure 5 shows all four objects at rest at the top of a slope. They are released at the same time and roll down the slope without slipping.

Figure 5



Deduce the order in which the objects reach the bottom of the slope.

[3 marks]

$v = \sqrt{2gh \div (1 + A)}$, so the greater A , the smaller v at any height and the longer the object takes to reach the bottom.

$$P: A = 2/5, \quad v = \sqrt{2gh \div 1.4} = \sqrt{10gh/7} = 3.7\sqrt{h} \text{ m s}^{-1}$$

$$Q: A = 2/3, \quad v = \sqrt{2gh \div 1.67} = \sqrt{6gh/5} = 3.4\sqrt{h} \text{ m s}^{-1}$$

$$R: A = 1/2, \quad v = \sqrt{2gh \div 1.5} = \sqrt{4gh/3} = 3.6\sqrt{h} \text{ m s}^{-1}$$

$$S: A = 1, \quad v = \sqrt{2gh \div 2} = \sqrt{gh} = 3.1\sqrt{h} \text{ m s}^{-1}$$

Descending order of v : $P > R > Q > S$

Order of reaching the bottom: P first, then R, then Q, and S last.

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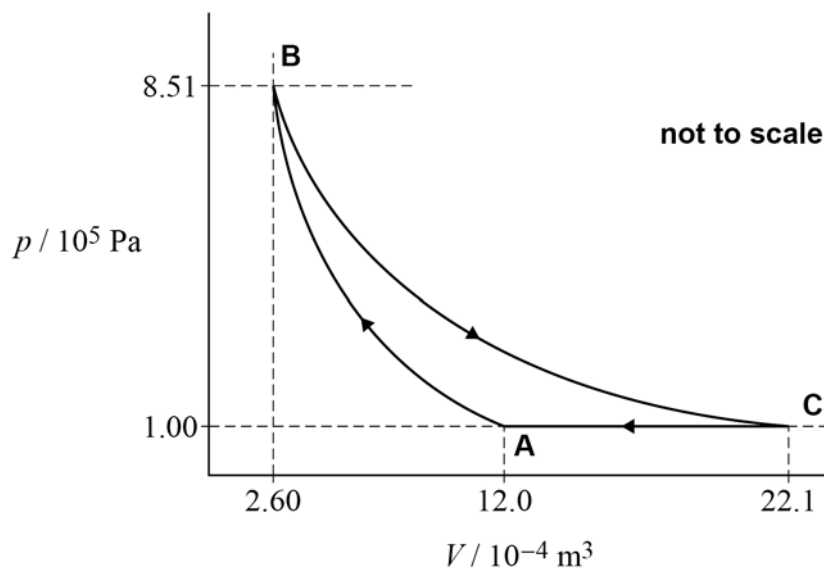
0 3 . 1

State what is meant by an isothermal change.

[1 mark]

A change of state of a gas that occurs at constant temperature.

Figure 6 shows a p - V diagram in which a fixed mass of an ideal gas is taken through a cycle of three processes.

A → **B**: adiabatic change**B** → **C**: isothermal change**C** → **A**: reduction in volume at constant pressure**Figure 6**

The maximum temperature of the gas in the cycle is 536 K and the minimum temperature is 291 K.

0 3 . 2

Calculate, in mol, the amount of gas.

[2 marks]

At B (536 K, maximum): $p = 8.51 \times 10^5 \text{ Pa}$, $V = 2.60 \times 10^{-4} \text{ m}^3$ *$pV = nRT$, so $n = pV \div RT$* *$n = (8.51 \times 10^5 \times 2.60 \times 10^{-4}) \div (8.31 \times 536)$* *$n = 221.3 \div 4454 = 4.97 \times 10^{-2} \text{ mol}$* amount of gas = 4.97×10^{-2} mol

0 3 . 3 Show that the work done in process **C** → **A** is about 100 J.

[1 mark]

$$W = p\Delta V = 1.00 \times 10^5 \times (12.0 - 22.1) \times 10^{-4} = -101 \text{ J}$$

(magnitude 101 J ≈ 100 J, work done on the gas)

0 3 . 4 Complete **Table 2** for each process and for the whole cycle.

[3 marks]

Table 2

	Q / J	W / J	$\Delta U / \text{J}$
Process A → B	0	-253	253
Process B → C	473	473	0
Process C → A	-354	-101	-253
Whole cycle	119	119	0

0 3 . 5 Two criteria for a heat engine to achieve the maximum theoretical efficiency are:

1. the gas must always be at the same temperature as the hot source when energy is being transferred **to** the gas by heat transfer
2. the gas must always be at the same temperature as the cold sink when energy is being transferred **from** the gas by heat transfer.

The temperatures of the source and sink do not change.

Deduce whether the cycle in **Figure 6** satisfies either or both of these criteria.

[2 marks]

Energy is transferred to the gas only in process B → C, which is

isothermal at 536 K, the maximum temperature (the hot source), so

criterion 1 is met. (A → B is adiabatic so there is no heat transfer.)

Energy is transferred from the gas in process C → A, at constant

pressure, during which the gas temperature falls from 536 K to 291 K,

so it is not always at the cold sink temperature. Criterion 2 is not met.

Question 3 continues on the next page

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0 3 . 6

The overall efficiency of a heat engine is defined as

$$\text{overall efficiency} = \frac{\text{net work output in one cycle}}{\text{energy supplied by heat transfer in one cycle}}$$

An engineer suggests designing a real engine based on the cycle shown in **Figure 6**.

Discuss the engineer's suggestion.

In your answer you should:

- use **Table 2** to determine the overall efficiency of a theoretical engine that uses the cycle
- compare this overall efficiency with the efficiency of an ideal engine working between the same temperatures as the cycle
- discuss with reasons the problems that would need to be overcome in making a real engine work on this cycle
- explain whether the engineer's suggestion would lead to a useful engine.

[6 marks]

$$\text{Overall efficiency} = 119 \div 473 = 0.25 \text{ (25\%)}$$

$$\text{Max efficiency} = (T_H - T_C) \div T_H = (536 - 291) \div 536 = 0.46 \text{ (46\%)}$$

Using Table 2, the net work done per cycle is 119 J and the energy supplied by heat transfer (in $B \rightarrow C$) is 473 J, so the overall efficiency of the theoretical engine is $119 \div 473 = 0.25$ (25%).

An ideal engine working between the same temperatures, 536 K and 291 K, has a maximum theoretical efficiency of $(536 - 291) \div 536 = 0.46$ (46%). So the efficiency of this cycle is much less than the maximum theoretical efficiency, because energy is lost from the gas over a range of temperatures in $C \rightarrow A$.

Problems in making a real engine work on this cycle: the adiabatic stroke $A \rightarrow B$ would have to be very fast so that there is no time for heat transfer, but the isothermal stroke $B \rightarrow C$ would have to be very slow to keep the temperature constant while energy is transferred to the



gas. It is very difficult to arrange a fast stroke and a slow stroke in the same engine, and the output speed would vary greatly over each cycle.

It is also difficult to arrange for the end of the expansion and the start of the compression to happen at one point; a real engine would need induction and exhaust (pumping) strokes to change the gas.

Engine valves take time and energy to open and close, and combustion of the fuel may be incomplete.

The engineer's suggestion would not lead to a useful engine. The net work done per cycle is very small (119 J, the area of the loop is small).

The real efficiency would be much lower than 25% because of friction and the problems above, and much lower than engines already available.

The slow isothermal stroke means there would be very few cycles per second, and since $\text{power} = \text{work done per cycle} \times \text{cycles per second}$, the power output would be very low.



0 4 . 1

State what is meant by the coefficient of performance of a heat pump.

[1 mark]

The ratio of the energy delivered (by heat transfer) to the hot space to the work input (energy supplied to run the pump).

A jeweller hopes to reduce workshop heating costs by replacing a gas-fired boiler with an electric heat pump. The heat pump will provide underfloor heating using water at a temperature of 40 °C.

The air outside the building provides the low-temperature reservoir for the heat pump. Over the winter period the outside temperature will vary between 12 °C and −8 °C.

The salesperson for a heat pump company claims that:

- the coefficient of performance will vary greatly, depending on the outside temperature
- the colder the outside temperature, the lower the energy costs will be for running the heat pump.

0 4 . 2

Comment on the salesperson's claims.

[3 marks]

$$COP_{hp} = T_H \div (T_H - T_C), \quad T_H = 40 + 273 = 313 \text{ K}$$

$$\text{At } 12 \text{ °C: } T_C = 285 \text{ K, } COP_{hp} = 313 \div (313 - 285) = 313 \div 28 = 11.2$$

$$\text{At } -8 \text{ °C: } T_C = 265 \text{ K, } COP_{hp} = 313 \div (313 - 265) = 313 \div 48 = 6.5$$

COP_{hp} depends on the temperature difference; it varies from 11.2 to 6.5, so the first claim is correct.

T_H is constant, so the lower T_C is, the greater the temperature difference and the lower the COP_{hp}. So more electrical energy (work) is needed to deliver the same heating, and the running costs are higher.

The second claim is incorrect.



0 4 . 3

A heat pump is installed. The average COP_{hp} over the winter period is 7.5
In this period the heat pump delivers 2880 kW h of underfloor heating.

What is the electrical energy used by the heat pump in this period?

Tick (✓) **one** box.

[1 mark]

333 kW h

☐

384 kW h

☒

2500 kW h

☐

21 600 kW h

☐

5

END OF QUESTIONS



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