

Please write clearly in block capitals.

Centre number

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Candidate number

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Surname

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Forename(s)

Candidate signature

A-level PHYSICS

Paper 3

Section B Engineering physics

Thursday 29 June 2017

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

5

TOTAL



J U N 1 7 7 4 0 8 3 B C 0 1

Section B

Answer **all** questions in this section.

0 1 . 1

There is an analogy between quantities in rotational and translational dynamics.

Complete **Table 1**, stating in words the quantities in rotational dynamics that are analogous to force and mass in translational dynamics.

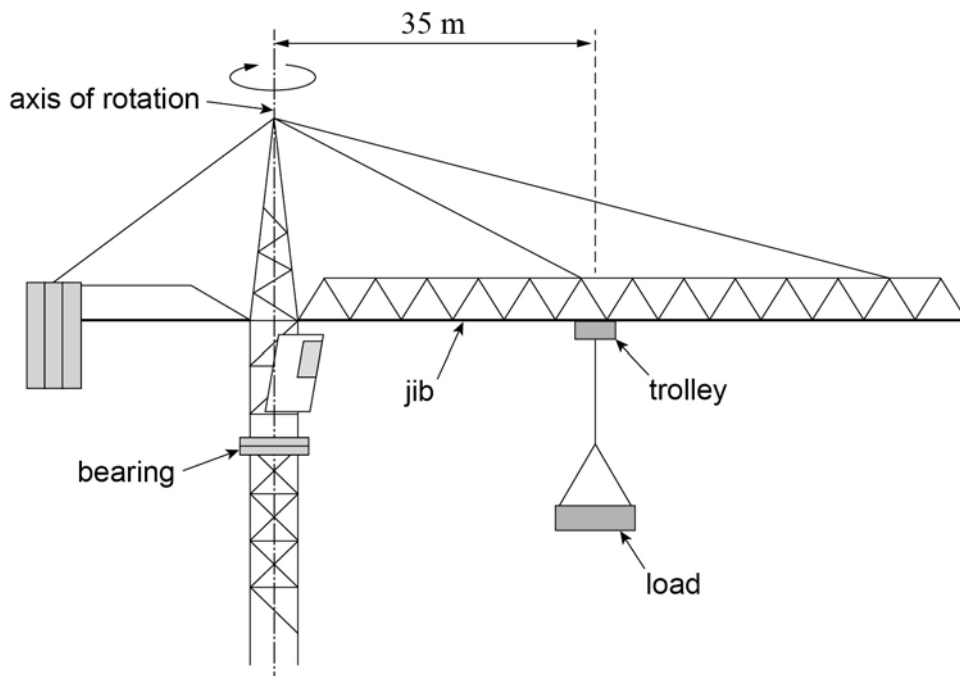
[2 marks]

Table 1

Translational dynamics	Rotational dynamics
force	<i>torque (moment of a force)</i>
mass	<i>moment of inertia</i>

Figure 1 shows a side view of the jib of a tower crane. The load is supported by a trolley which can move along the jib. The jib consists of all the parts of the crane above the bearing, but excluding the trolley and load.

Figure 1



The moment of inertia of the jib about the axis of rotation = $2.6 \times 10^7 \text{ kg m}^2$

Mass of trolley and load = $2.2 \times 10^3 \text{ kg}$



0 1 . 2

The load is at a distance of 35 m from the axis of rotation.

Show that the total moment of inertia of the jib, and the trolley and load, about the axis of rotation is about $3 \times 10^7 \text{ kg m}^2$.

[1 mark]

$$\begin{aligned}
 I_{\text{total}} &= I_{\text{jib}} + mr^2 \\
 &= 2.6 \times 10^7 + (2.2 \times 10^3 \times 35^2) \\
 &= 2.6 \times 10^7 + 2.7 \times 10^6 \\
 &= 2.87 \times 10^7 \approx 2.9 \times 10^7 \text{ kg m}^2 \text{ (about } 3 \times 10^7 \text{ kg m}^2)
 \end{aligned}$$

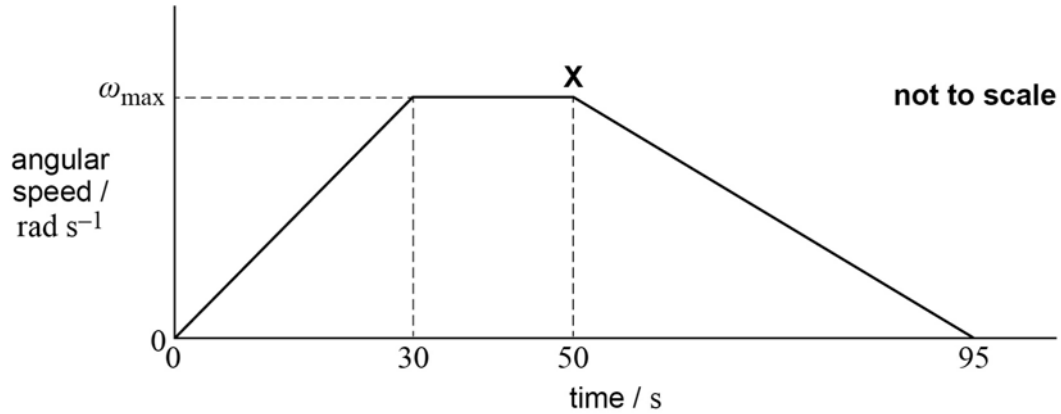
Question 1 continues on the next page

Turn over ►



0 1 . 3

Figure 2 shows the variation of angular speed of the jib as it turns through an angle of 4.7 rad (270°) in a total time of 95 s . The trolley and load remain at a distance of 35 m from the axis.

Figure 2

Calculate the maximum angular speed $\omega_{\max}$ of the jib.

[2 marks]

angle turned = area under ω - t graph (angular displacement)

$$4.7 = \omega_{\max} \times \left(\frac{1}{2} \times 30\right) + \omega_{\max} \times 20 + \omega_{\max} \times \left(\frac{1}{2} \times 45\right)$$

$$4.7 = 57.5 \omega_{\max}$$

$$\omega_{\max} = 4.7 \div 57.5 = 0.0817 \text{ rad s}^{-1}$$

maximum angular speed = 0.082 rad s^{-1}



0 1 . 4

At time **X** in **Figure 2** the motor that is driving the jib is disengaged. A constant braking torque is then applied to bring the jib to a standstill from its maximum angular speed.

The crane driver repeats the movement of the jib with the same load at 35 m from the axis of rotation. Up to time **X** the motion is the same as before. From time **X** the trolley is driven at a steady speed away from the axis as the jib continues to rotate until the jib comes to a standstill.

Assume the braking torque remains the same as before.

Discuss how the motion of the trolley affects the time taken for the jib to come to a standstill.

[3 marks]

As the trolley and load move outwards, the moment of inertia of the rotating system (jib + trolley + load) increases, since $I = \sum mr^2$ and r increases.

The braking torque T is constant and $T = I\alpha$, so as I increases the angular deceleration α decreases.

A smaller deceleration from the same ω_{max} means the jib takes longer to stop, so it comes to a standstill later than 95 s (more than 45 s after X).

8

Turn over for the next question

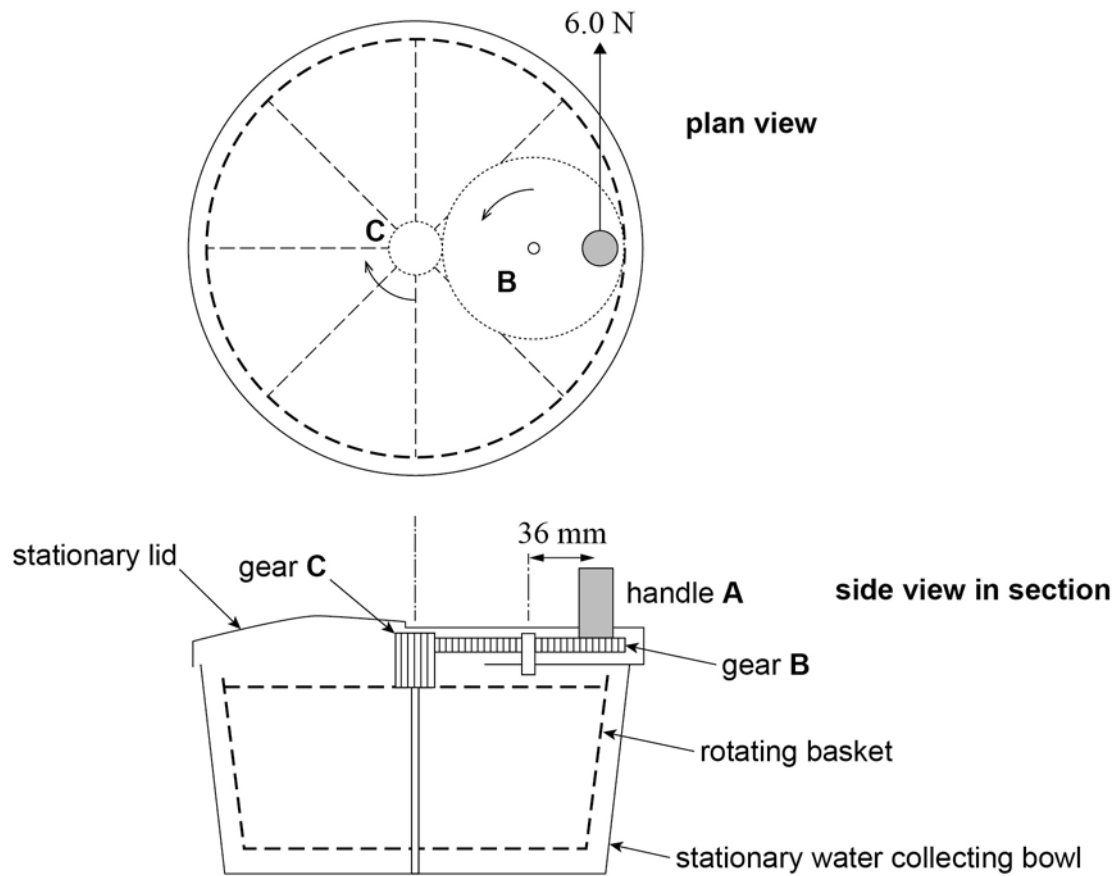
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0 2

Figure 3 shows the basic principle of operation of a hand-operated salad spinner used to dry washed salads.

Figure 3



The salad is placed in the basket and the lid is attached.

When handle **A** is turned the basket and its contents spin rapidly. Water on the salad is driven through holes in the basket into the stationary water collecting bowl. The pivot for gear **B** is fixed to the lid. This pivot and the lid do not move. When gear **B** rotates, gear **C** also rotates but at a greater angular speed. Gear **C** is fixed to the basket and rotates it.

A force of 6.0 N is applied to handle **A** as shown. Handle **A** is at a radius of 36 mm from its centre of rotation.



0 2 . 1

Calculate the input torque.

[1 mark]

$$T = Fr = 6.0 \times 0.036$$

torque = 0.22 N m

0 2 . 2

Gear **C** rotates four times for every one revolution of gear **B**.Deduce whether it is possible for the torque on gear **C** to be greater than one quarter of the input torque.

[2 marks]

No. The power output of gear C cannot be greater than the power input to gear B (energy cannot be created).

$P = Tw$ and ω_C is $4 \times \omega_B$, so T_C cannot be more than $\frac{1}{4}$ of the input torque (it equals $\frac{1}{4}$ only if there are no losses).

0 2 . 3

It takes 2.1 s for the empty basket to reach an angular speed of 76 rad s^{-1} . The torque on gear **C** is a constant 0.054 N m during this time. Frictional losses are negligible.

Calculate the moment of inertia of the basket about its axis of rotation.

[2 marks]

$$\alpha = \Delta\omega / t = 76 \div 2.1 = 36.2 \text{ rad s}^{-2}$$

$$T = I\alpha \text{ so } I = T / \alpha = 0.054 \div 36.2$$

$$I = 1.49 \times 10^{-3} \text{ kg m}^2$$

moment of inertia = 1.5×10^{-3} kg m²

Question 2 continues on the next page

Turn over ►



0 2 . 4

The gears are made from polymer (plastic). An early version of this salad spinner suffered from damaged gear teeth.

Explain with reference to angular impulse why a great force is put on the gear teeth if the user tries to stop the loaded basket too quickly using the handle.

[3 marks]

Angular impulse = change in angular momentum = $T\Delta t$.

The loaded basket has a large angular momentum $l\omega$. Stopping it too

quickly means this large change in angular momentum $\Delta(l\omega)$ happens

in a very small time Δt , so the torque $T = \Delta(l\omega)/\Delta t$ is very large.

Since $T = F \times r$ and the gear radius is small, a large torque means

a very large force F on the gear teeth, which can damage the

polymer teeth.



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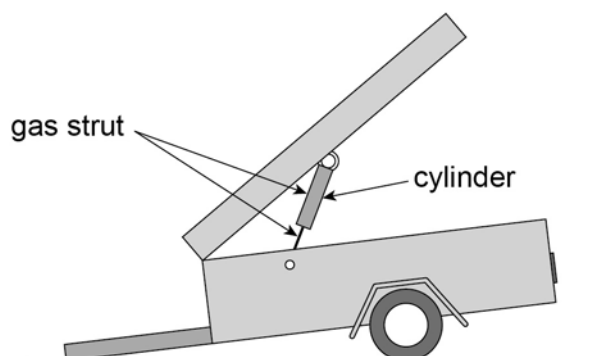
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0 3

Figure 4 shows a gas strut supporting the lid of a trailer.

Figure 4



A fixed mass of nitrogen gas is sealed into the cylinder of the strut.

0 3 . 1

The gas is initially at a pressure of 1.2×10^6 Pa, a volume of $9.0 \times 10^{-5} \text{ m}^3$ and a temperature of 290 K.

When the lid is closed quickly the gas is compressed rapidly to a final volume of $6.8 \times 10^{-5} \text{ m}^3$.

Calculate the pressure and temperature of the gas at the end of the compression assuming the compression to be an adiabatic process.

adiabatic index γ for nitrogen = 1.4

[4 marks]

$$\text{Adiabatic: } pV^\gamma = \text{constant, so } p_1V_1^{1.4} = p_2V_2^{1.4}$$

$$p_2 = p_1(V_1/V_2)^{1.4} = 1.2 \times 10^6 \times (9.0/6.8)^{1.4}$$

$$p_2 = 1.78 \times 10^6 \text{ Pa} \approx 1.8 \times 10^6 \text{ Pa}$$

$$p_1V_1/T_1 = p_2V_2/T_2 \text{ so } T_2 = p_2V_2T_1 / p_1V_1$$

$$T_2 = (1.78 \times 10^6 \times 6.8 \times 10^{-5} \times 290) / (1.2 \times 10^6 \times 9.0 \times 10^{-5})$$

$$T_2 = 324 \text{ K}$$

pressure = 1.8×10^6 Pa

temperature = 324 K



0 3 . 2

Explain why the rapid compression of the gas can be assumed to be an adiabatic process.

[2 marks]

In an adiabatic process there is no heat transfer to or from the gas ($Q = 0$).

The compression is so quick that there is no time for heat to be transferred from the gas to the cylinder and surroundings, so it can be considered adiabatic.

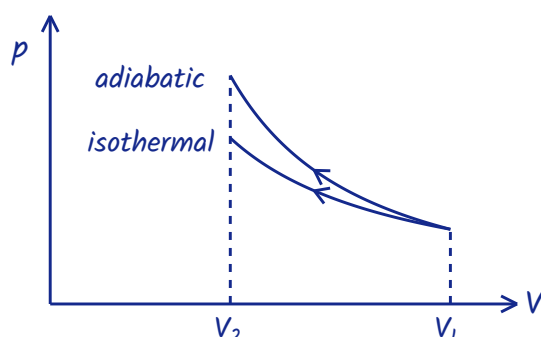
0 3 . 3

When the lid is closed slowly, the compression can be assumed to be isothermal.

The gas can be compressed either isothermally or adiabatically from the same initial conditions to the same final volume.

Compare without calculation the work done in each process.

[3 marks]



*Work done = area under curve:
area under adiabatic
curve is larger*

For the same change in volume, the final pressure is not as high in the isothermal compression: the adiabatic compression curve on the p-V diagram is steeper than the isothermal curve.

The work done is the area under the p-V curve between the same two volumes (the sum of all $p\Delta V$ during compression), so the area under the isothermal curve is less.

So less work is done on the gas in the isothermal compression than in the adiabatic compression.

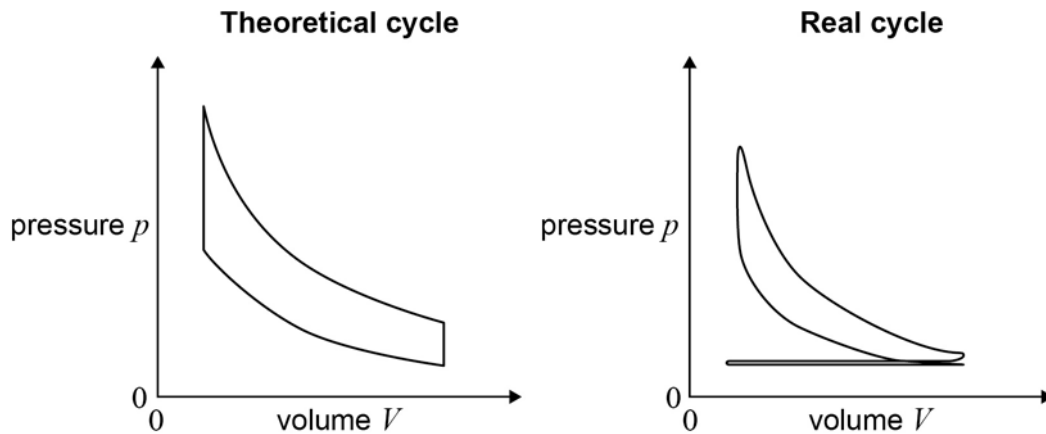
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0 4

Figure 5 shows the p – V diagram for a theoretical petrol engine cycle compared to the indicator diagram for a real four-stroke petrol engine with the same maximum and minimum volumes.

Figure 5



Compare the theoretical and real engine cycles. In your answer you should:

- state and explain the differences between the cycles
- explain why the work output per cycle of the real engine is less than that predicted by an analysis of the theoretical cycle.

[6 marks]

Differences: the real cycle has an extra thin pumping loop at low pressure. This is because a real four-stroke engine needs induction and exhaust strokes to draw in fresh fuel-air mixture and push out the exhaust gases. The theoretical cycle has no pumping loop, as the same air is assumed to be used repeatedly.

The corners of the real cycle are rounded, whereas the theoretical cycle has sharp corners. This is because the valves take a finite time to open and close, and combustion of the fuel is not instantaneous.

In the theoretical cycle, heating and cooling happen at constant volume (the vertical lines). This cannot happen in the real cycle because the piston would have to stop; in reality the piston keeps moving while the fuel burns and while the exhaust valve opens.



In the real cycle the expansion and compression are not adiabatic, because heat is transferred from the gas to the cylinder walls and the cooling medium during these strokes. The theoretical cycle assumes both are adiabatic.

The theoretical cycle assumes only air, behaving as an ideal gas, is taken through the cycle repeatedly. In the real engine the gas is a mixture of air, fuel vapour and exhaust gas, which is not ideal (and γ varies during expansion and compression).

The maximum pressure in the real engine is lower, as the fuel may not be completely burnt.

The theoretical cycle makes no reference to any mechanism, but the real engine needs a mechanism, e.g. for valve operation and generation of the spark.

Why the work output is less: the work done per cycle is the area enclosed by the loop. The main loop of the real cycle is smaller (rounded corners, lower maximum pressure, heat losses), so less work is done per cycle.

The area of the pumping loop is work done on the gas during induction and exhaust, so it has to be subtracted from the area of the main loop, reducing the net work done.

Also, work is done against friction between moving surfaces, e.g. between the piston and cylinder and in the bearings, and energy is used to drive the oil and water pumps and to open and close the valves, overcoming fluid viscosity. So the useful work output per cycle of the real engine is less than the theoretical prediction.

Turn over for the next question

Turn over ►



0 5 . 1

An ideal heat pump and an ideal refrigerator operate between the same hot and cold spaces.

Which statement relating to the coefficient of performance (COP) is correct?
Tick (✓) the correct answer.

[1 mark]

The COP of the refrigerator must be < 1 .

☐

The COP of the heat pump must be greater than the COP of the refrigerator.

☒

The COP of the heat pump will increase if the temperature of the hot space is increased.

☐

The COP of the refrigerator will decrease if the cold space temperature increases.

☐

0 5 . 2

An ideal refrigerator operates between a cold space at a temperature of $-1\text{ }^{\circ}\text{C}$ and a hot space at a temperature of $70\text{ }^{\circ}\text{C}$.

Calculate the input power to the refrigerator if the rate of transfer of energy to the hot space is 100 W .

[3 marks]

$$T_c = -1 + 273 = 272\text{ K}, \quad T_h = 70 + 273 = 343\text{ K}$$

$$\text{COP}_{\text{ref}} = T_c / (T_h - T_c) = 272 / (343 - 272) = 3.83$$

$$\text{COP}_{\text{ref}} = Q_c / W \text{ and } Q_c + W = Q_h = 100\text{ W}$$

$$3.83\text{ W} + W = 100 \text{ so } 4.83\text{ W} = 100$$

$$W = 100 \div 4.83 = 20.7\text{ W} \quad (Q_c = 79.3\text{ W})$$

input power = 21 W

4

END OF QUESTIONS



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