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 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** | |

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**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.

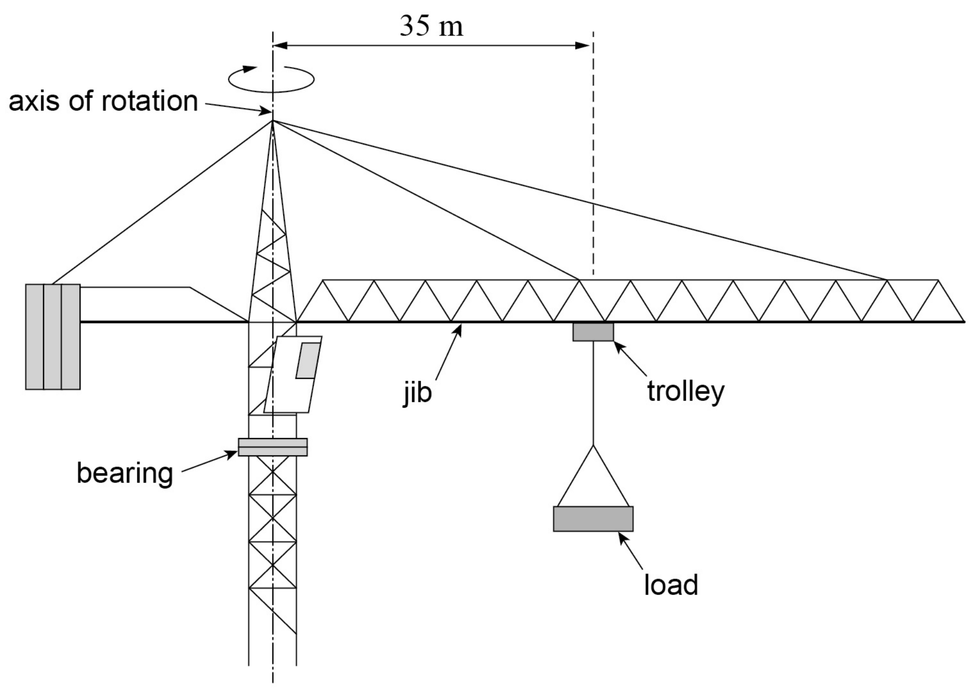
**[2 marks]**

**Table 1**

| Translational dynamics | Rotational dynamics |
|---|---|
| force | torque ✓ |
| mass | moment of inertia ✓ |

**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 = $2.6 \times 10^7$ kg m$^2$

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

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**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 $3 \times 10^7$ kg m$^2$.

**[1 mark]**

moment of inertia of trolley and load

$(2.6\times10^7) + I_L$

$= (2.6\times10^7) + M_L R_L^2$

mass　radius from axis

$= (2.6\times10^7) + (2.2\times10^3 \times 35^2) = 2.9\times10^7\,kgm^2$

$\simeq 3\times10^7\,kgm^2$ ✓

**Question 1 continues on the next page**

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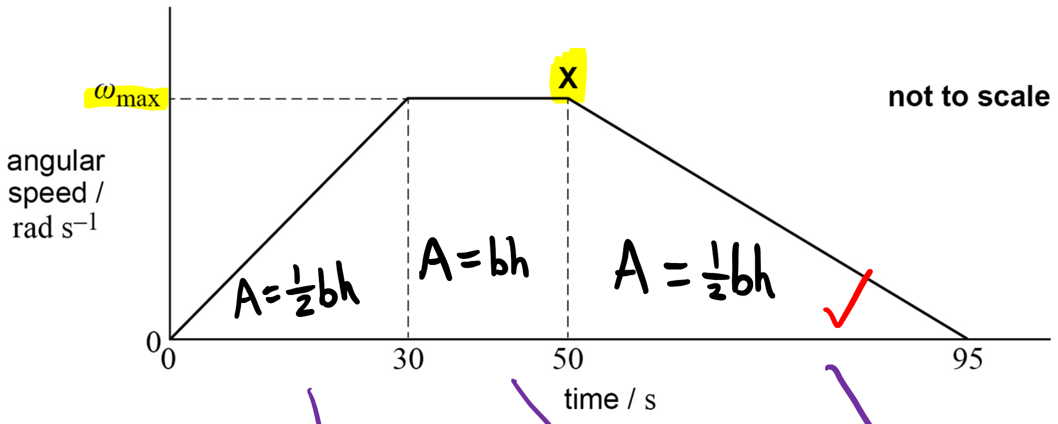
**0 1 . 3** **Figure 2** shows the variation of angular speed of the jib as it turns through an angle of $4.7$ rad ($270°$) in a total time of $95$ s. The trolley and load remain at a distance of $35$ m from the axis.

**Figure 2**




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

**[2 marks]**

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

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

$$\omega_{max} = \frac{4.7}{\left(\tfrac{1}{2} \times 30\right) + 20 + \left(\tfrac{1}{2} \times 45\right)} = 0.082 \text{ rad.s}^{-1}$$

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

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**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]**

$T = I\alpha$ — angular acceleration

torque, moment of inertia

• Moment of inertia is equal to $mr^2$ (mass times radius squared), so increasing r will also increase the moment of inertia of the load (and therefore the total moment of inertia) ✓

• Keeping torque constant will mean that the angular acceleration is lower ✓ (or angular deceleration)

• Decreasing α means that the crane takes longer to stop ✓

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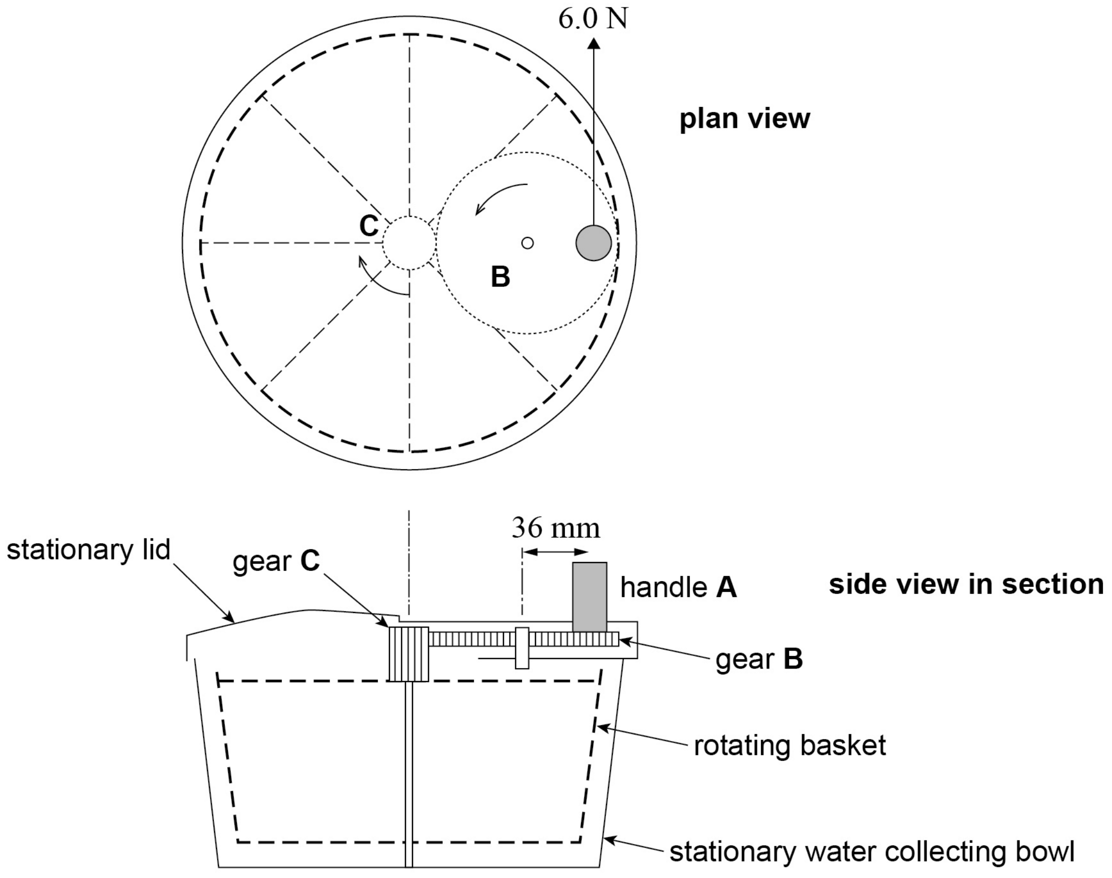
**Turn over for the next question**

**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]**

36mm = 0.036m

T = 6.0 × 0.036 = 0.22 Nm

torque  force  radius

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]**

Conservation of energy ; power does not change ✓

power  torque  angular speed

P = Tω

The angular speed multiplies by 4, so torque is one quarter of earlier value. It cannot be more than this. ✓

**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]**

angular acceleration

$\alpha = \frac{\Delta\omega}{\Delta t}$ — angular velocity, time

$\alpha = \frac{76}{2.1} = 36.2 \text{ rad s}^{-2}$ ✓

torque  moment of inertia

$T = I\alpha \Rightarrow I = \frac{T}{\alpha} = \frac{0.054}{36.2} = 1.5\times10^{-3} \text{ kgm}^2$

moment of inertia = $1.5\times10^{-3}$ ✓ kg $m^2$

**Question 2 continues on the next page**

**Turn over ▶**

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**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]**

Linear impulse = force X change in time

Angular impulse = $T\Delta t$ = $\Delta$(angular momentum) ✓

torque — time

$\Delta t \propto \frac{1}{T}$, so a small time of torque application (with a constant change in angular momentum) will give a high torque ✓

torque — force

$T = Fr$ — radius, so a high torque at a constant radius will mean a high force is exerted on the gear teeth ✓

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**Turn over for the next question**

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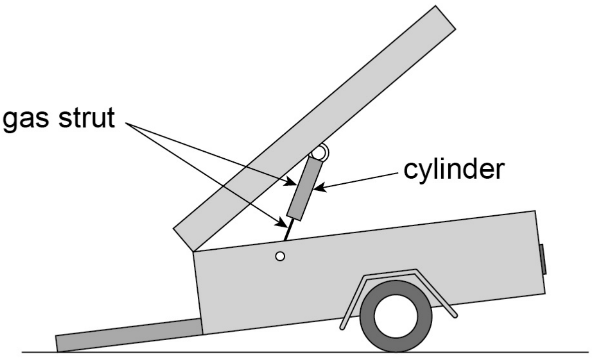
**0 3** **Figure 4** shows a gas strut supporting the lid of a trailer.

**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 $1.2 \times 10^{6}$ Pa, a volume of $9.0 \times 10^{-5}$ m$^3$ and a temperature of 290 K.

When the lid is closed quickly the gas is compressed rapidly to a final volume of $6.8 \times 10^{-5}$ 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 $\gamma$ for nitrogen = 1.4

**[4 marks]**

① $p_1V_1^{1.4} = p_2V_2^{1.4} \Rightarrow p_2 = \frac{p_1V_1^{1.4}}{V_2^{1.4}} = \frac{1.2\times10^6 \times 9.0^{1.4}}{6.8^{1.4}}$ ✓

pressure, volume

$= 1.8\times10^6$ Pa

② $pV = nRT$ — temperature (K)

no. of moles, molar gas constant

$\frac{pV}{T} = \text{constant}$

$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$

$T_2 = \frac{p_2V_2}{p_1V_1}T_1$

$= \frac{1.8\times10^6 \times 6.8\times10^{-5}}{1.2\times10^6 \times 9.0\times10^{-5}} \times 290$ ✓

pressure = $1.8\times10^6$ ✓ Pa

temperature = 328 ✓ K

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**0 3 . 2** Explain why the rapid compression of the gas can be assumed to be an adiabatic process.

**[2 marks]**

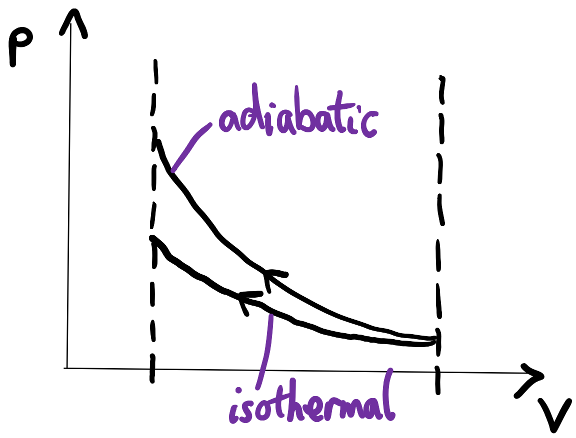
· An adiabatic process is one in which there is no heat transfer. ✓
· If the compression is rapid, it takes place in a short time, so there is no time for heat to be transferred. ✓

**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]**




· The adiabatic curve is steeper than the isothermal curve for a given volume change ✓
· The area under the adiabatic curve will be greater for a given volume change ✓
· More work is done via the adiabatic compression ✓

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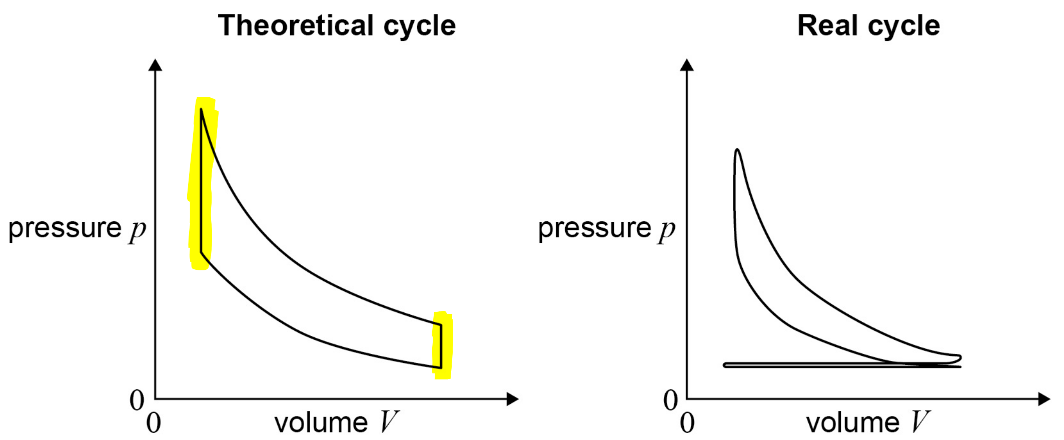
**0 4** **Figure 5** shows the $p-V$ diagram for a theoretical petrol engine cycle compared to the indicator diagram for a real four-stroke petrol engine with the same maximum and minimum volumes.

**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 Between Cycles

• In the real cycle, the corners are rounded.
→ The valves cannot open and close in zero time; there is time required for these changes.

• The theoretical cycle has straight vertical lines, which imply constant volume during heating and cooling
→ The piston would need to stop for this to happen

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• In the ideal cycle, only ideal gas is taken in
→ Not all of the gas is necessarily ideal in the real cycle, there may be vapour present

Work Output per Cycle

• The work done is given by the area of the loop, so this is lower in the real cycle
• Moving parts in the real engine have friction, so the work output is lower
• The work output is reduced when energy is needed to drive water and oil pumps, and open and close valves

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**Turn over for the next question**

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**0 5 . 1** An ideal heat pump and an ideal refrigerator operate between the same hot and cold spaces. $T_H > T_c$

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. $= \frac{T_H}{T_H - T_c}$ , $\frac{T_c}{T_H - T_c}$ | ✓ |
| 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 °C and a hot space at a temperature of 70 °C.
(−1 °C = 272 K; 70 °C = 343 K)

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

**[3 marks]**

$$COP_{ref} = \frac{T_c}{T_H - T_c} = \frac{272}{343 - 272} = 3.83$$ ✓

($COP_{ref}$ – coefficient of performance of refrigerator; $T_c$ – temperature of cold space; $T_H$ – temperature of hot space)

$$COP_{ref} = \frac{Q_c}{Q_H - Q_c}$$

($Q_c$ – power taken from cold space; $Q_H$ – power supplied to hot space)

$$Q_c = \frac{Q_H COP_{ref}}{1 + COP_{ref}} = \frac{100 \times 3.83}{1 + 3.83} = 79.3\text{W}$$ ✓

$$W = Q_H - Q_c = 100 - 79.3 = 20.7\text{W}$$

input power = 21 ✓ W

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**END OF QUESTIONS**

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