AQA

Please write clearly in block capitals.

Centre number | | | | | | Candidate number | | | | |

Surname ______________________

Forename(s) ______________________

Candidate signature ______________________
I declare this is my own work.

A-level
PHYSICS

Paper 3
Section B Engineering physics

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	
5	
TOTAL	

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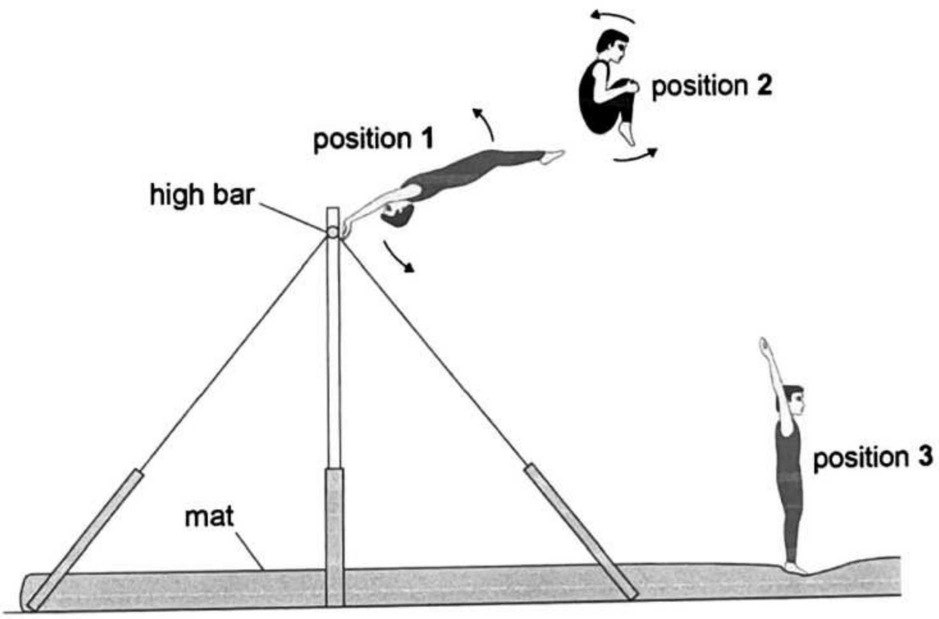
Section B

Answer **all** questions in this section.

0 1 A gymnast dismounts from an exercise in which he swings on a high bar. The gymnast rotates in the air before landing.

Figure 1 shows the gymnast in three positions during the dismount.

Figure 1



The arrows show the direction of rotation of the gymnast.

In position **1** the gymnast has just let go of the bar. His body is fully extended.

Position **2** shows the rotating gymnast a short time later. His knees have been brought close to his chest into a 'tuck'.

Position **3** is at the end of the dismount as the gymnast lands on the mat. His body is once again fully extended.

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0 1 . 1 Explain why the moment of inertia about the axis of rotation decreases when his knees are moved towards his chest.
Go on to explain the effect this has on his angular speed.

[3 marks]

The moment of inertia decreases because there is more mass closer to the axis of rotation in position 2. The angular momentum is constant because there is no external torque. Because $L = I\omega$, the angular speed must increase.

Table 1 gives some data about the gymnast in position **1** and in position **2**.

Table 1

Position	Moment of inertia / kg m^2	Angular speed / rad s^{-1}
1	13.5	ω
2	4.1	14.2

0 1 . 2 Calculate the angular speed ω of the gymnast in position **1**.

[1 mark]

$I_1\omega_1 = I_2\omega_2$

$\omega_1 = \frac{I_2}{I_1}\omega_2 = \frac{4.1}{13.5} \times 14.2 = 4.3$ rad s^{-1}

ω = 4.3 rad s^{-1}

Question 1 continues on the next page

Turn over ▶

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0 1 . 3 The gymnast stays in the tuck for 1.2 s.

Determine the number of **complete** rotations performed by the gymnast when in the tuck during the dismount.

[2 marks]

θ turned = 1.2 × 14.2 = 17.04 rad.

number of rotations = $\frac{17.04}{2\pi}$ = 2.7 rotations.

number of complete rotations = 2.

0 1 . 4 The gymnast repeats the exercise. The height of the bar remains unchanged.

State and explain **two** actions the gymnast can take to complete more rotations during the dismount.

[4 marks]

1 Get into the tuck position earlier to increase the amount of time turning.

2 Get into a tighter tuck position, reducing I_2 and hence increasing ω_2.

10

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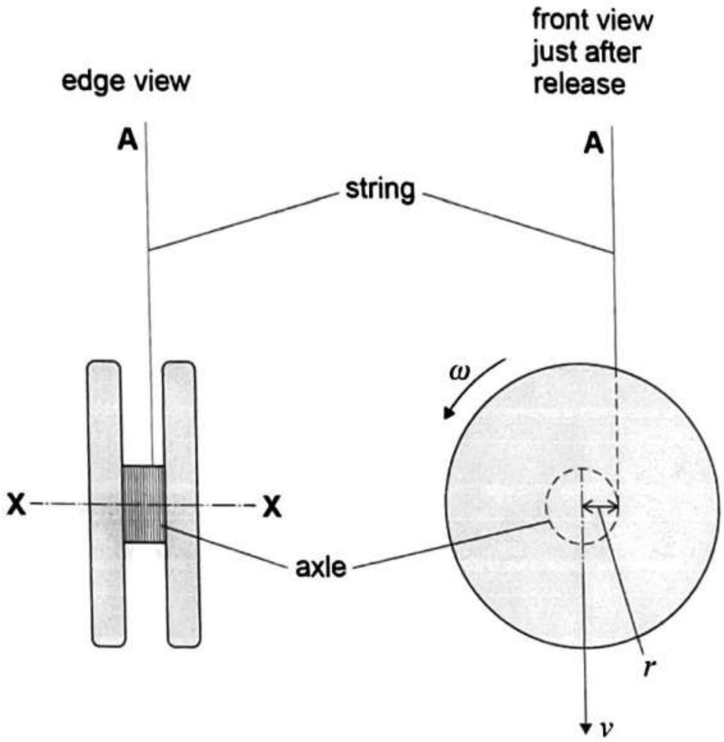
0 2 **Figure 2** shows a yo-yo made of two discs separated by a cylindrical axle. Thin string is wrapped tightly around the axle.

Figure 2



Initially both the free end **A** of the string and the yo-yo are held stationary.

With **A** remaining stationary, the yo-yo is now released so that it falls vertically. As the yo-yo falls, the string unwinds from the axle so that the yo-yo spins about its centre of mass.

The linear velocity v of the centre of mass of the falling yo-yo is related to the angular velocity ω by $v = r\omega$ where r is the radius of the axle.

Question 2 continues on the next page

0 2 . 1 The yo-yo accelerates uniformly as it falls from rest. The string remains taut and has negligible thickness.

mass of yo-yo = 9.2×10^{-2} kg
radius of axle = 5.0×10^{-3} m
moment of inertia of yo-yo about axis **X-X** = 8.6×10^{-5} kg m^2

When the yo-yo has fallen a distance of 0.50 m, its linear velocity is V.

Calculate V by considering the energy transfers that occur during the fall.

[3 marks]

initial E_p = linear E_k + rotational E_k

$mg\Delta h = \frac{1}{2}mV^2 + \frac{1}{2}I\omega^2$

$mg\Delta h = \frac{1}{2}mV^2 + \frac{1}{2}I\left(\frac{V}{r}\right)^2$

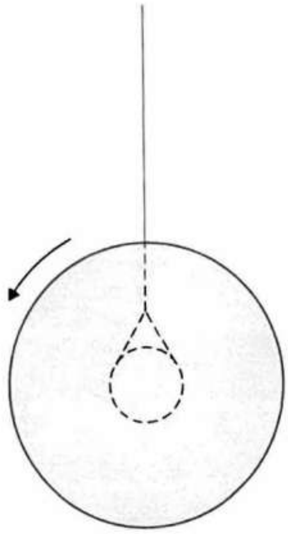
$9.2 \times 10^{-2} \times 9.81 \times 0.5 = \frac{1}{2} \times 9.2 \times 10^{-2} \times V^2 + \frac{1}{2} \times (8.6 \times 10^{-5}) \times \frac{V^2}{0.005^2}$

$V = 0.51 ms^{-1}$

V = 0.51 m s^{-1}

0 2 . 2 The yo-yo falls further until all the string is unwound. The yo-yo then 'sleeps'. This means the yo-yo continues to rotate in a loose loop of string as shown in **Figure 3**.

Figure 3



The string applies a constant frictional torque of 8.3×10^{-4} N m to the axle.
The angular velocity of the yo-yo at the start of the sleep is 145 rad s^{-1}.

Determine, in rad, the total angle turned through by the yo-yo during the first 10 s of sleeping.

[3 marks]

$T = I\alpha$

$\alpha = \frac{T}{I} = \frac{8.3\times10^{-4}}{8.6\times10^{-5}} = 9.65$ rads^{-1}

$\theta = 145\times10 - \frac{1}{2}\times 9.65\times10^2 = 968$ rad

angle = 968 rad

6

0 3 **Figure 4** shows the results of a test on an internal combustion engine which uses purified biogas.

Figure 4

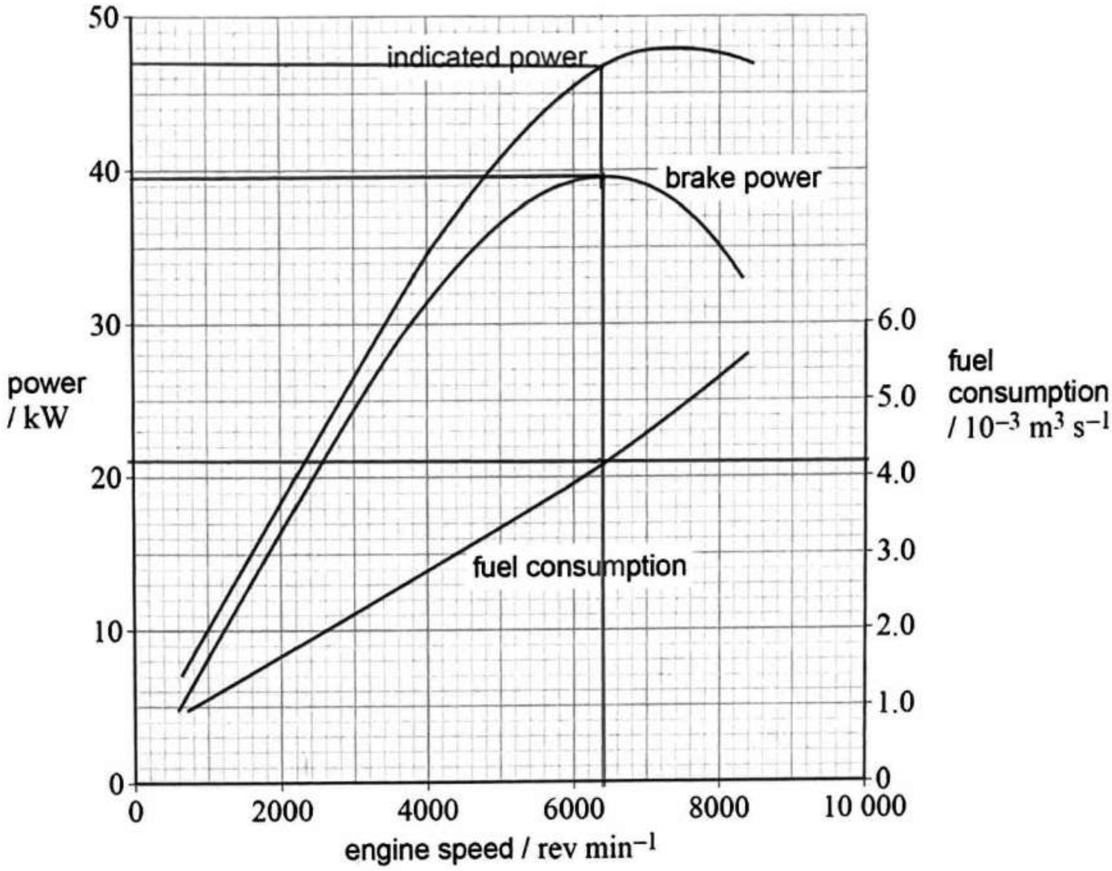


Figure 4 shows how the indicated power, brake (or output) power and fuel consumption of the engine vary with the engine speed. The scale on the left-hand axis is power and the scale on the right-hand axis is fuel consumption.

0 3 . 1 **Figure 4** can be used to analyse the performance of the engine.

Determine, for the speed at which the engine develops its maximum brake power:

- the overall efficiency
- the thermal efficiency
- the mechanical efficiency.

Go on to explain how knowledge of these efficiencies can be useful to an engineer.

calorific value of biogas used in the test = 32.3×10^6 J m^{-3}

[6 marks]

max break power at 6400 rev min^{-1}

Fuel consumption = ~~[illegible]~~ 4.2×10^{-3} m^{3}s^{-1}

brake power = 39.5 kW

indicated power = 47 kW.

input power = $32.3 \times 10^6 \times 4.2 \times 10^{-3} = 136$ kW.

Overall efficiency = $\frac{\text{brake power}}{\text{input power}}$

$= \frac{39.5}{136} = 0.29$

Thermal efficiency = $\frac{\text{indicated power}}{\text{input power}}$

$= \frac{47}{136} = 0.35$

mechanical efficiency = $\frac{\text{brake power}}{\text{indicated power}}$

$= \frac{39.5}{47} = 0.84$

Friction power = indicated power − brake power

$= 47 - 39.5 = 7.5$ kW.

Answer space continues on the next page

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The thermal efficiency indicates how well the calorific value of fuel is converted into power in the engine.

mechanical efficiency indicates how well the engine uses power to overcome friction in the engine and to operate the valves, pumps etc.

Overall efficiency indicates how well energy in fuel is converted into useful work output.

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0 3 . 2 Explain why it is **not** advisable to run this engine at speeds above 7000 rev min^{-1}.
Refer to **Figure 4** in your answer.

[2 marks]

The brake power decreases whilst the input power continues to increase so the efficiency of the engine decreases.

8

Turn over for the next question

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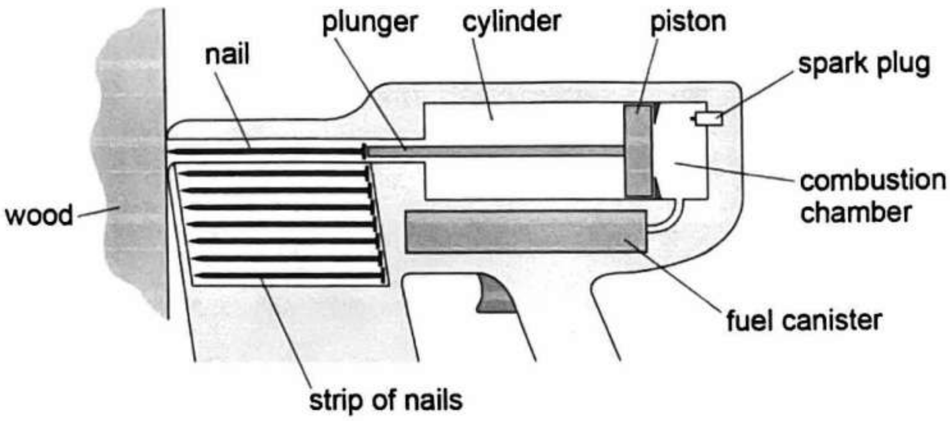
0 4 **Figure 5** shows a tool for driving nails into wood. Only part of the tool is shown.

Figure 5



Fuel is mixed with air in the combustion chamber and is ignited by a spark. The gas expands rapidly and drives the piston along the cylinder. The plunger attached to the piston drives the nail into the wood.

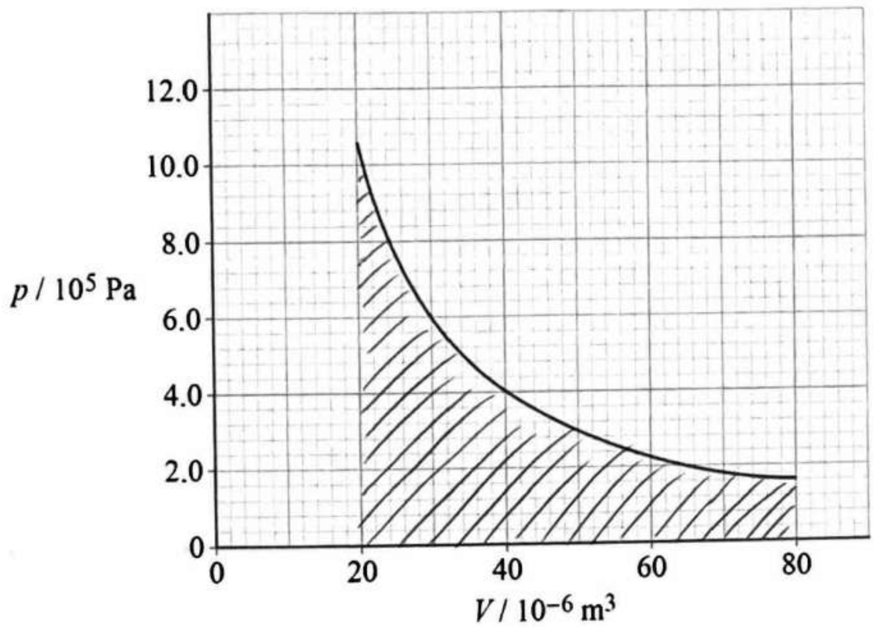
Table 2 shows the average force needed to drive nails of various lengths completely into a particular type of wood.

Table 2

Nail	Length / mm	Average force / N
A	32	250
B	38	320
C	45	370
D	50	420
E	63	560

0 4 . 1 **Figure 6** shows the variation of pressure p with volume V as the gas expands on the right-hand side of the piston when the correct nail is used.

Figure 6



The combustion chamber has a volume of 20×10^{-6} m^3 and the piston moves through a volume of 60×10^{-6} m^3.

The work done by the expanding gas is just enough to drive the correct nail completely into the wood.

Deduce which nail in **Table 2** is the correct one to use in the tool.

[5 marks]

Area under graph = 23 J.

$W = F \times S$

$W_A = 250 \times 0.032 = 8$ J

$W_B = 320 \times 0.038 = 12$ J

$W_C = 370 \times 0.045 = 17$ J

$W_D = 420 \times 0.050 = 21$ J

$W_E = 560 \times 0.063 = 35$ J.

Nail D. E needs more work whereas A, B, C need less

Question 4 continues on the next page

0 4 . 2 After a nail has been used, another nail takes its place automatically. The tool can drive up to 180 nails per minute.

Discuss why the expansion **cannot** be isothermal.

[3 marks]

isothermal expansion requires a relatively long time to take place. because it requires energy transfer for the temperature to remain constant. The nail is fired in $< 1/3$ s and so the expansion occurs very quickly so there is not enough time for this energy transfer.

8

0 5 . 1 Which is a correct statement about an ideal heat engine?
Tick (✓) **one** box.

[1 mark]

- [ ] The efficiency is increased when the kelvin temperatures of the hot source and the cold sink are increased by equal amounts.
- [ ] The maximum efficiency depends on the p–V cycle.
- [x] The efficiency is 50% when the kelvin temperature of the hot source is twice the kelvin temperature of the cold sink.

0 5 . 2 An ideal heat engine has an efficiency of 0.33
The same engine works in reverse as an ideal refrigerator between the same hot and cold spaces.

Determine the coefficient of performance COP_{ref} of the refrigerator.

[2 marks]

$Q_H = 3 \times W$

$Q_C = Q_H - W = 0.67 Q_H.$

$COP_{ref} = \frac{Q_C}{W} = 2.$

COP_{ref} = 2

3

END OF QUESTIONS