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

Friday 5 June 2020 Afternoon

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.
- 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.

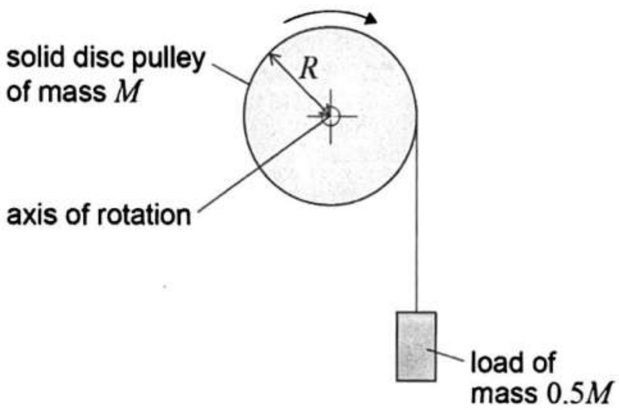
0 1 . 1 State what is meant by the moment of inertia of an object about an axis.

[1 mark]

It is the sum of all constituent masses x their radius / distance from the axis squared

0 1 . 2 A student does an experiment using the apparatus shown in **Figure 1**.

Figure 1



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A solid disc pulley of mass M and radius R is supported in bearings which have negligible friction.

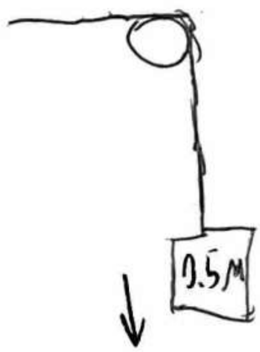
A string of negligible mass is wrapped around the circumference of the pulley.
A load of mass $0.5M$ is fixed to the free end of the string. The string does not slip on the pulley.
The moment of inertia of the pulley about the axis of rotation is $0.5MR^2$.
The student holds the pulley stationary.

When the student releases the pulley, the load accelerates downwards uniformly and is at a velocity v after moving a distance h.

Show that the acceleration of the load is $0.5g$.

[4 marks]

E_p lost = E_k pulley + E_k mass



$0.5Mgh = \frac{1}{2}(0.5M)v^2 + \frac{1}{2}(0.5MR^2)\omega^2$

$gh = \frac{1}{2}v^2 + \frac{1}{2}R^2\omega^2$

$\omega = \frac{v}{R}$

s u v a t

$v^2 = u^2 + 2as$

$v^2 = 2ah$

$gh = \frac{1}{2}v^2 + \frac{1}{2}v^2$

$gh = v^2$

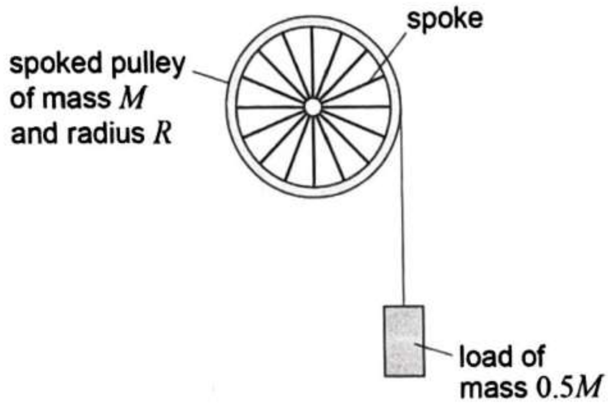
~~$gh = 2gh$~~

$gh = 2ah \rightarrow a = \frac{g}{2} = 0.5g$

Question 1 continues on the next page

0 1 . 3 The student repeats the experiment using a spoked pulley of the same mass and radius, as shown in **Figure 2**.

Figure 2



Compare the acceleration of the load in this experiment with its acceleration in the previous experiment.
A calculation is **not** required.

[3 marks]

The moment of inertia of the spoked pulley is greater because due to the spokes, it is not solid like the previous experiment. This means the mass is ~~spread~~ concentrated around the spoked pulleys outer edge. This means there is a greater proportion of the E_p loss given to the pulley. The velocity of the mass in the same time is hence lower so the acceleration is lower.

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0 2 . 1 State the condition necessary so that the law of conservation of angular momentum applies to a rotating system.

[1 mark]

No net external torque acts on the system.

A clutch is used to connect two rotating shafts together so that they rotate at the same speed.

0 2 . 2 **Figure 3** shows two shafts, **A** and **B**, rotating freely about the same axis.
Table 1 gives information about the two shafts.

Figure 3

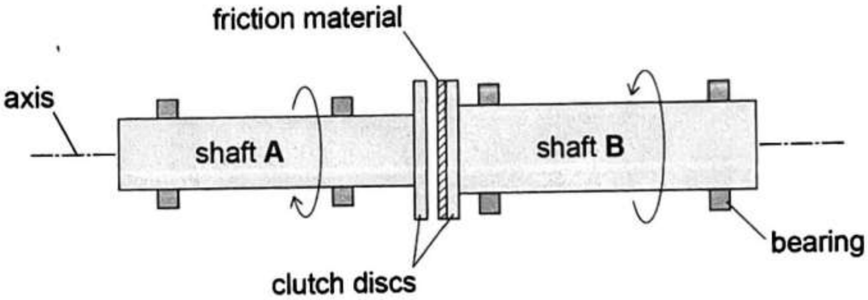

Table 1

	Shaft **A**	Shaft **B**
Angular speed / rad s^{-1}	95	45
Moment of inertia / kg m^2	7.2	11.5
Direction of rotation	Clockwise looking from left	Anticlockwise looking from left

The two shafts are connected by forcing the clutch discs together.
Friction acts between the discs and slipping occurs for a short time until both shafts rotate at a common angular speed.
The clutch is now said to be engaged.

Show that the common angular speed of the two shafts immediately after the clutch is engaged is about 9 rad s^{-1}.

State whether the direction of the common angular speed is clockwise or anticlockwise when viewed from the left.

[3 marks]

$I_A w_A + I_B w_B = (I_a + I_B) w$

$7.2 \times 95 + 11.5 \times -45 = 18.7w$

$w = 8.9$ rad s^{-1} Clockwise

direction when viewed from the left = Clock wise

Question 2 continues on the next page

0 2 . 3 **Table 2** gives information about two clutches, **C** and **D**.
C and **D** provide different constant frictional torques during slipping at the clutch discs.

Table 2

Clutch	Frictional torque during slipping / N m
C	600
D	320

The slipping time is to be kept between 1.0 s and 2.0 s with the same initial conditions shown in **Table 1**, and the same final common angular speed.

Deduce whether either or both clutches allow this.

[3 marks]

angular impulse = $T\Delta t = \Delta(I\omega)$

For clutch C: $600t = 7.2 \times (95-8.9) =$ ~~[illegible]~~ Nms

$t = 1.03$ s

For clutch D: $320t = 7.2 \times (95-8.9)$

$t = 1.937$ s

Both clutches satisfy the criteria as the slipping time is between

$1\text{s} < t < 2\text{s}$

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Maths Made Easy

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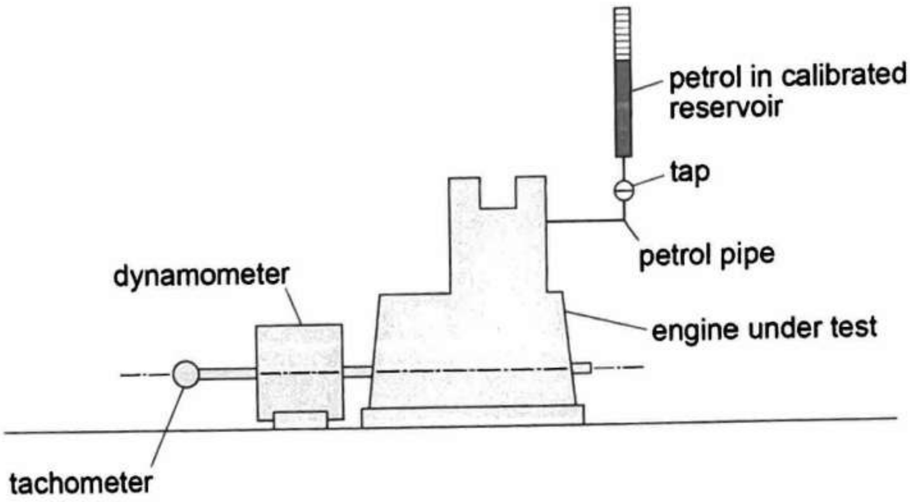
0 3 **Figure 4** shows some of the equipment used to investigate the thermal and mechanical efficiencies of a single-cylinder four-stroke petrol engine.

Figure 4



- Petrol is supplied to the engine from a calibrated reservoir.
- Sensors are used to measure the volume V and pressure p above the piston inside the cylinder.
- The dynamometer applies a load to the output shaft and measures the output torque of the engine.
- The tachometer measures the rotational speed of the engine in revolutions per second.

In one test the air intake valve (throttle) setting remains fixed and the load provided by the dynamometer is kept constant.

Describe how you would determine the input power, the indicated power, the brake power, the thermal efficiency and the mechanical efficiency.

In your answer you should
- describe the measurements that you would take
- show how you would use the measurements and any other necessary data.

[6 marks]

One of the measurements that would need to be taken is ~~the~~ the input power. This can be done by measuring the volume of fuel used in a given time using the reservoir and a stop watch. This can be ~~as~~ used to calculate

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the input power by multiplying the the calorific value of fuel by the fuel flow rate.
Another measurement that is needed is the indicated power. For this the cylinder pressures and volumes are needed. Using a p-V diagram, sensors can be used to determine the area of the diagram. This is then multiplied by the speed from the tachometer and a 1/2.
We would also need the brake output power. We can measure the torque on the output shaft using the ~~tachometer~~ dynamometer and the engine speed using the tachometer. We can then multiply tachometer reading by 2π.

These values can then be used to calculate the thermal efficiency by dividing the indicated power by the input power, we can calculate the mechanical efficiency = brake power / indicated power. Thus we have determined all the key values.

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0 4 . 1 Which row in **Table 3** shows

- **Process 1** in which work done is zero, and
- **Process 2** in which the change in internal energy is zero?

Tick (✓) **one** box.

[1 mark]

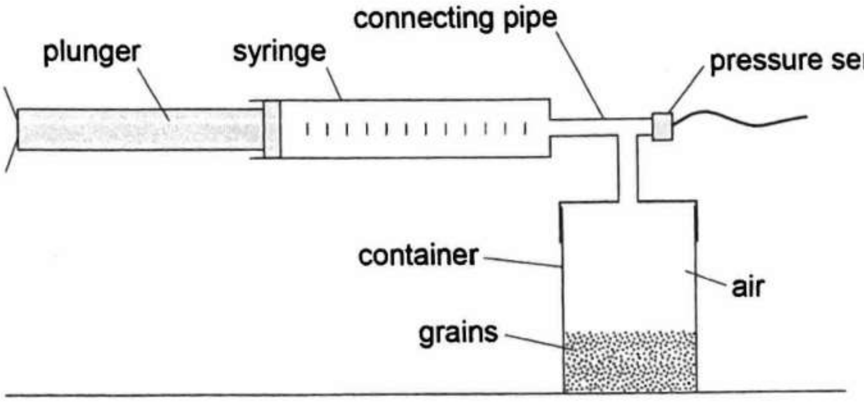
Table 3

Process 1	Process 2	
constant pressure	isothermal	☐
constant volume	adiabatic	☐
constant pressure	adiabatic	☐
constant volume	isothermal	✓

0 4 . 2 When irregular particles are packed, air gaps are left between the particles. The true volume of a quantity of irregular particles must be determined using a method that does not include the volume of the air spaces between them.

The apparatus shown in **Figure 5** is used by an agricultural engineer to measure the true volume of some grains.

Figure 5



The volume of air in the syringe is 1.00×10^{-4} m^3.
The volume of the **empty** container and connecting pipe is 2.80×10^{-4} m^3.
Grains of total true volume V are now placed in the container and the lid is screwed on.
The pressure inside both the syringe and the container is 1.01×10^5 Pa.
The plunger is slowly pushed fully into the cylinder of the syringe, compressing the air isothermally.
The pressure increases to 1.83×10^5 Pa.

Determine V.

[3 marks]

$pV =$ constant $\quad p_1V_1 = p_2V_2$

$(1.00 \times 10^{-4} + 2.80 \times 10^{-4} - V)\ 1.01 \times 10^5$

$= 1.83 \times 10^5 \times (2.80 \times 10^{-4} - V)$

Leading to $V = 1.57 \times 10^{-4}$ m^3

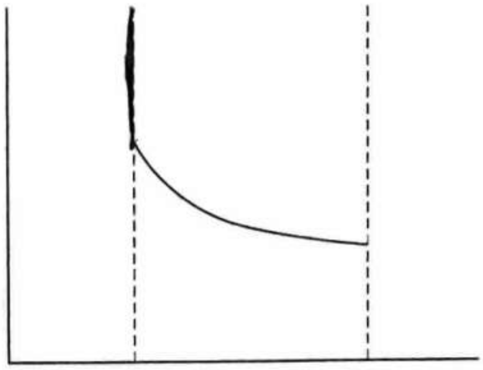
$V =$ 1.57×10^{-4} m^3

Question 4 continues on the next page

Turn over ▶

Figure 6 shows how the pressure in the container and syringe varies with volume as the plunger is pushed in fully very slowly.

Figure 6



0 4 . 3 Sketch on **Figure 6** the variation of pressure with volume when the plunger is pushed in fully very quickly and then left for several seconds.
Assume no leakage past the plunger.

[2 marks]

0 4 . 4 Explain why the compression of a gas can be considered to be an isothermal change when the gas is compressed very slowly.

[2 marks]

In an isothermal process, for the thermal energy to remain constant, an energy transfer must take place. If it is a slow enough isothermal change; then there is sufficient time for this transfer to take place.

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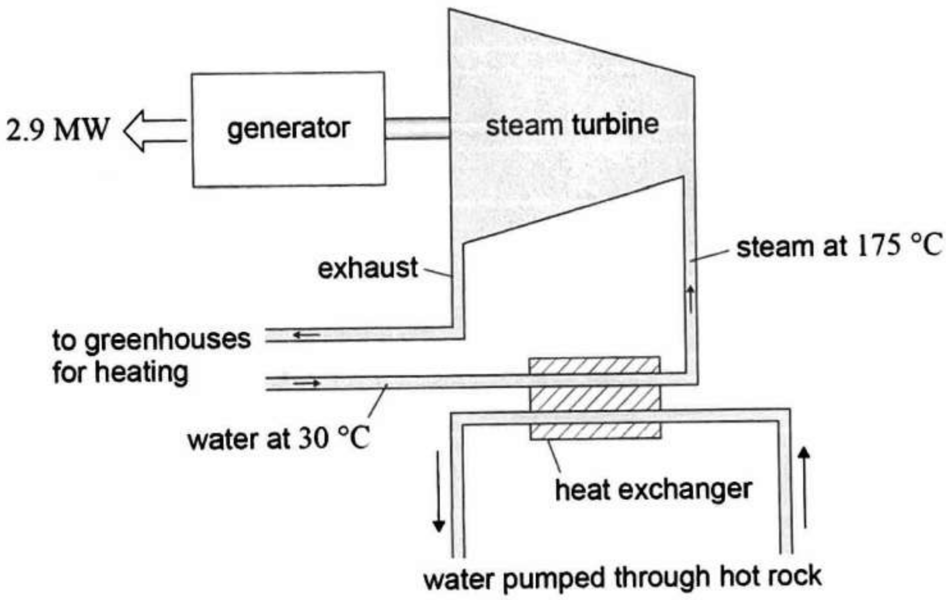
0 5 . 1 Explain how the second law of thermodynamics predicts that a heat engine can never be 100% efficient.

[2 marks]

For the 2nd law of thermodynamics to apply, an engine must operate between hot and cold reservoirs. Therefore it must refuse some ~~cold~~ energy to the cold reservoir.

0 5 . 2 A company plans to build a geothermal power station in a region where there is hot rock deep below the surface. The scheme is shown in **Figure 7**.

Figure 7



In the heat exchanger, energy from the hot rock is used to produce steam at 175 °C.
The steam passes through a turbine that drives an electric generator.
The exhaust steam is used to heat nearby greenhouses where it condenses before returning to the heat exchanger.

The lowest temperature in the turbine cycle is 30 °C.

The company claims that when the electrical power output is 2.9 MW, the power station will provide 6.4 MW for heating the greenhouses.

Deduce whether this claim is likely to be true.
Treat the power station as an ideal heat engine which obeys the second law of thermodynamics.

[4 marks]

$175°C = 448 K$ $30°C = 303 K$

~~max~~ theoretical efficiency $= \frac{T_H - T_C}{T_H}$

$\eta = \frac{448 - 303}{448} = 0.32$

$\eta = \frac{W}{Q_c + W}$ also, so $Q_c = \frac{W}{\eta} - W$

$Q_c = \frac{2.9}{0.32} - 2.9 = 6.2 MW$

6.2MW < 6.4MW so the claim is false

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END OF QUESTIONS