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Forename(s) ______________________

Candidate signature ______________________

I declare this is my own work.

INTERNATIONAL A-LEVEL

PHYSICS

Unit 5 Physics in practice

Thursday 19 January 2023 07:00 GMT Time allowed: 2 hours

Materials

For this paper you must have:

- a Data and Formulae Booklet as a loose insert
- a ruler with millimetre measurements
- a scientific calculator, which you are expected to use where appropriate
- 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.
- All working must be shown.
- 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.

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 80.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
TOTAL	

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Section A

Answer **all** questions in this section.

0 1 Fuse wire is designed to melt when the current in the wire reaches a certain value. The fusing current I_F is the minimum current that will cause a length of fuse wire to melt.

0 1 . 1 A student is provided with a length of fuse wire and normal electrical equipment.

Figure 1 shows the circuit symbol for a length of fuse wire.

Figure 1

Draw a suitable circuit diagram that the student can use to determine I_F.

[2 marks]

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0 1 . 2 The student is provided with five samples of fuse wire. The five wires are all made from the same material but have different diameters.

Theory suggests that I_F is related to the diameter D by

$$I_F = k\,D^{1.5} \text{ where } k \text{ is a constant.}$$

Describe how the student could use the circuit that you have drawn in Question **01.1** to test the validity of this equation.

Your answer should include:

- the measurements to be taken and the apparatus needed
- details of the procedure
- how to test the validity of the equation.

[5 marks]

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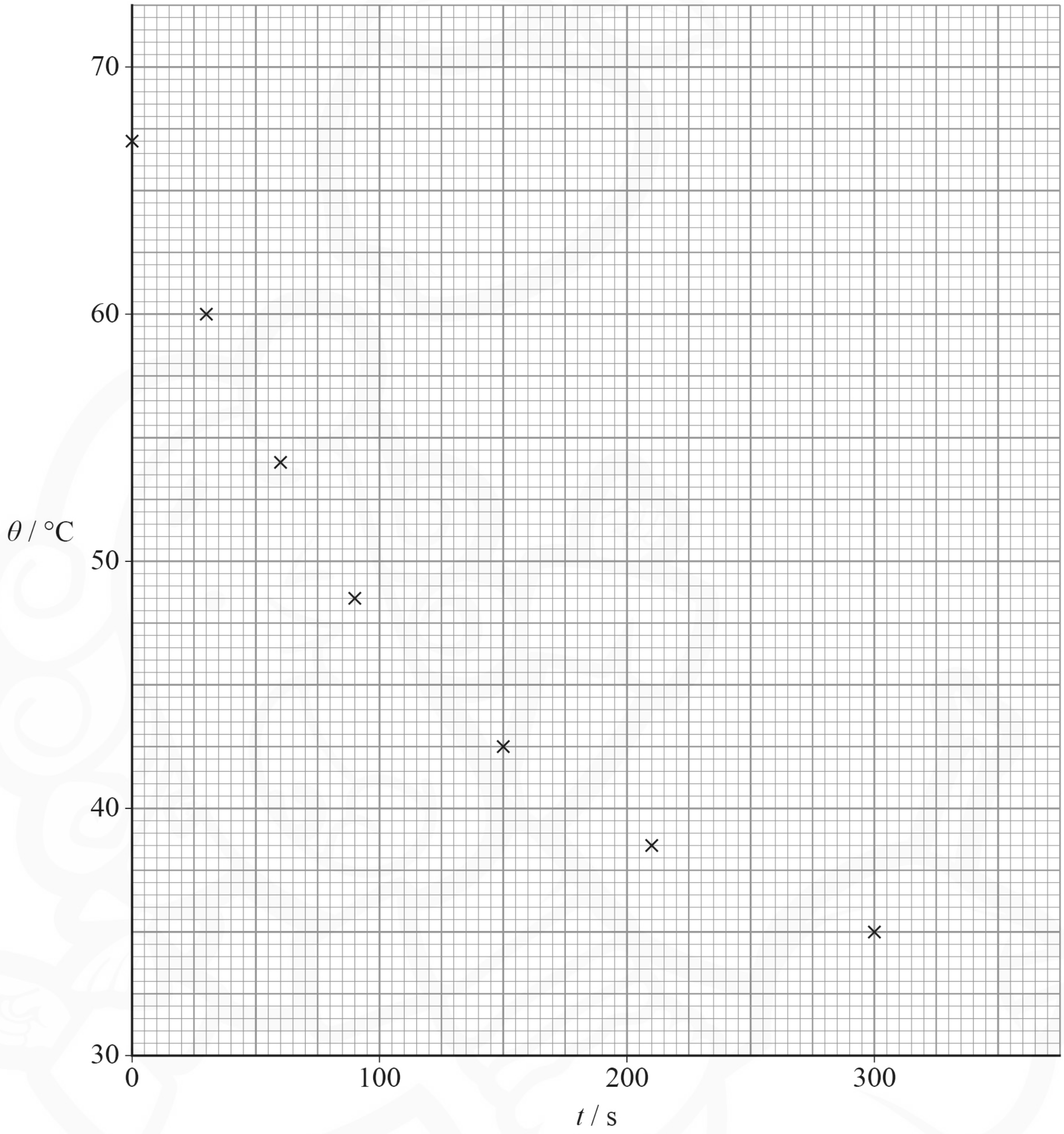
0 2 A student is investigating the cooling of oil. She puts $250\ \text{g}$ of hot oil into a metal container and records the temperature θ of the oil for $300\ \text{s}$ as it cools.

Figure 2 is a plot of θ against time t for the cooling oil.

Figure 2



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0 2 . 1 Explain **one** feature of the container that will ensure a maximum rate of heat transfer from the oil to the surroundings at any given temperature difference.

[1 mark]

____

____

0 2 . 2 Draw the line of best fit for the data plotted in **Figure 2**.

[1 mark]

0 2 . 3 Explain how **Figure 2**, together with other data, can be used to determine the total heat transfer from the oil during the first 300 s.

[2 marks]

____

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0 2 . 4 Show that the rate of change of temperature of the oil at a temperature of 45 °C is approximately $0.1\ \mathrm{K\ s^{-1}}$.

[2 marks]

0 2 . 5 At a temperature of 45 °C, the rate of heat transfer from the oil is $54\ \mathrm{J\ s^{-1}}$.

Calculate the specific heat capacity of the oil.

[2 marks]

specific heat capacity = ______________________ $\mathrm{J\ kg^{-1}\ K^{-1}}$

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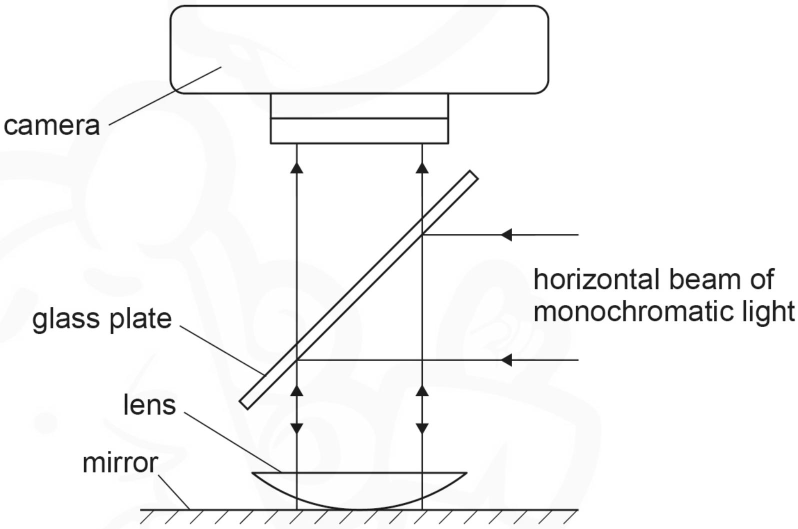
0 3 **Figure 3** shows apparatus that a student uses to measure the wavelength of a horizontal beam of monochromatic light.

The light is initially reflected downwards by a glass plate towards a lens and a mirror. The light travels through the lens.
The lower surface of the lens reflects some of the light upwards.
The rest of the light continues to the mirror and is reflected upwards at the mirror surface.

Light from the lower surface of the lens and light from the mirror surface then superpose to form a circular interference pattern that is photographed.

Figure 3



Question 3 continues on the next page

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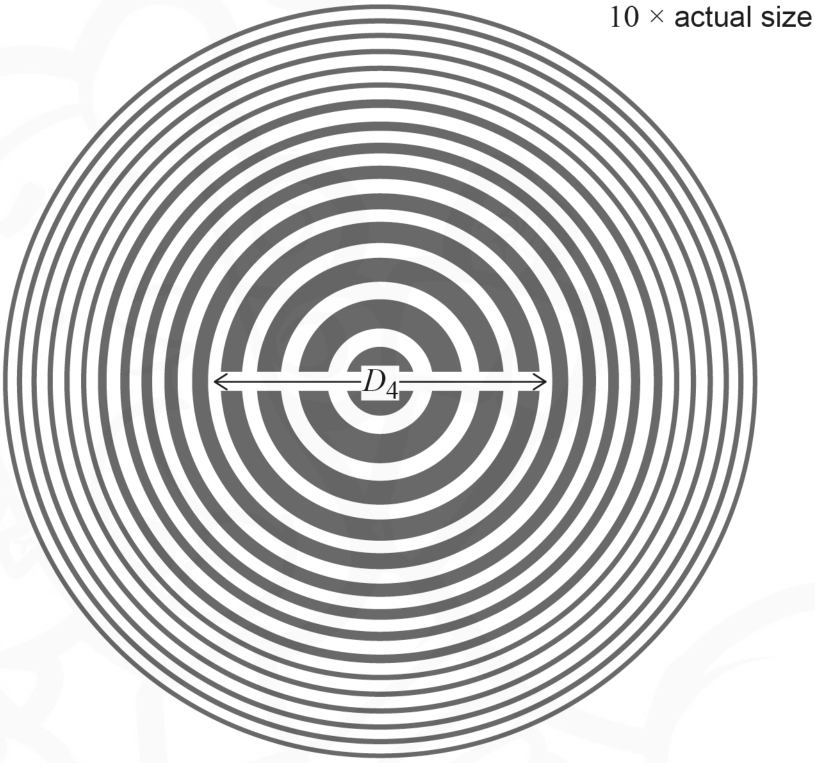
Figure 4 shows an actual-size photograph of the interference pattern.
The pattern is a series of bright and dark circles called rings.

Figure 4

The diameter of the nth bright ring on this actual-size photograph is d_n. For example, the diameter of the 4th bright ring is d_4.

The student makes a magnified image of the interference pattern that is **10 times larger** than the actual size. **Figure 5** shows the magnified image.

Figure 5



The diameter of the 4th bright ring, counting from the centre of the **magnified** image, is D_4.

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0 3 . 1 The student uses a millimetre scale to measure D_4 from the image in **Figure 5**. The student measures D_4 as 44 mm.

Calculate the percentage uncertainty in D_4.

[1 mark]

uncertainty in $D_4 = \pm$ ____________________ %

0 3 . 2 Calculate, using your answer to Question **03.1**, the absolute uncertainty in d_4^2.

[2 marks]

absolute uncertainty in $d_4^2 = \pm$ ____________________ mm^2

0 3 . 3 Determine, using **Figure 5**, an accurate value for d_9, the actual diameter of the 9th bright ring.

[2 marks]

$d_9 =$ ____________________ mm

The wavelength λ of the monochromatic light is given by $\lambda = \dfrac{d_9^2 - d_4^2}{20r}$

where $r = (3.40 \pm 0.01)$ m = the radius of the curved surface of the lens in **Figure 3**.

0 3 . 4 Calculate λ.

[1 mark]

$\lambda =$ ____________________ m

Question 3 continues on the next page

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0 3 . 5 Calculate the percentage uncertainty in your value for λ.

Assume that the absolute uncertainty in d_9^2 is the same as the absolute uncertainty in d_4^2 calculated in Question **03.2**.

[3 marks]

uncertainty in λ = ____________________ %

0 3 . 6 Explain **one** advantage of using **Figure 5** rather than **Figure 4** to determine λ.

[1 mark]

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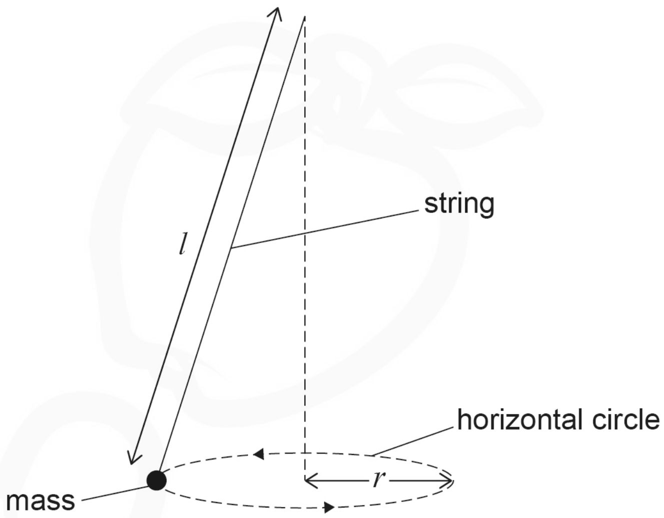
0 4 **Figure 6** shows a mass on the end of a string. The mass rotates freely in a horizontal circle at a constant speed.

Figure 6



0 4 . 1 State and explain the origin of the centripetal force acting on the mass.

[1 mark]

The period of rotation T of the mass is measured for a range of values of the length l of the string.
The radius r of the circle is kept constant as l is varied.

0 4 . 2 **Table 1** shows measurements of l and T and some derived data from the experiment.

Table 1

l / m	T / s	$\sqrt{(l^2 - r^2)}$ / m	T^2 / s^2
0.600	1.55	0.587	2.40
0.700	1.67	0.689	2.79
0.800	1.79	0.790	3.20
0.900	1.90	0.891	3.61
1.000	2.01	0.992	4.04

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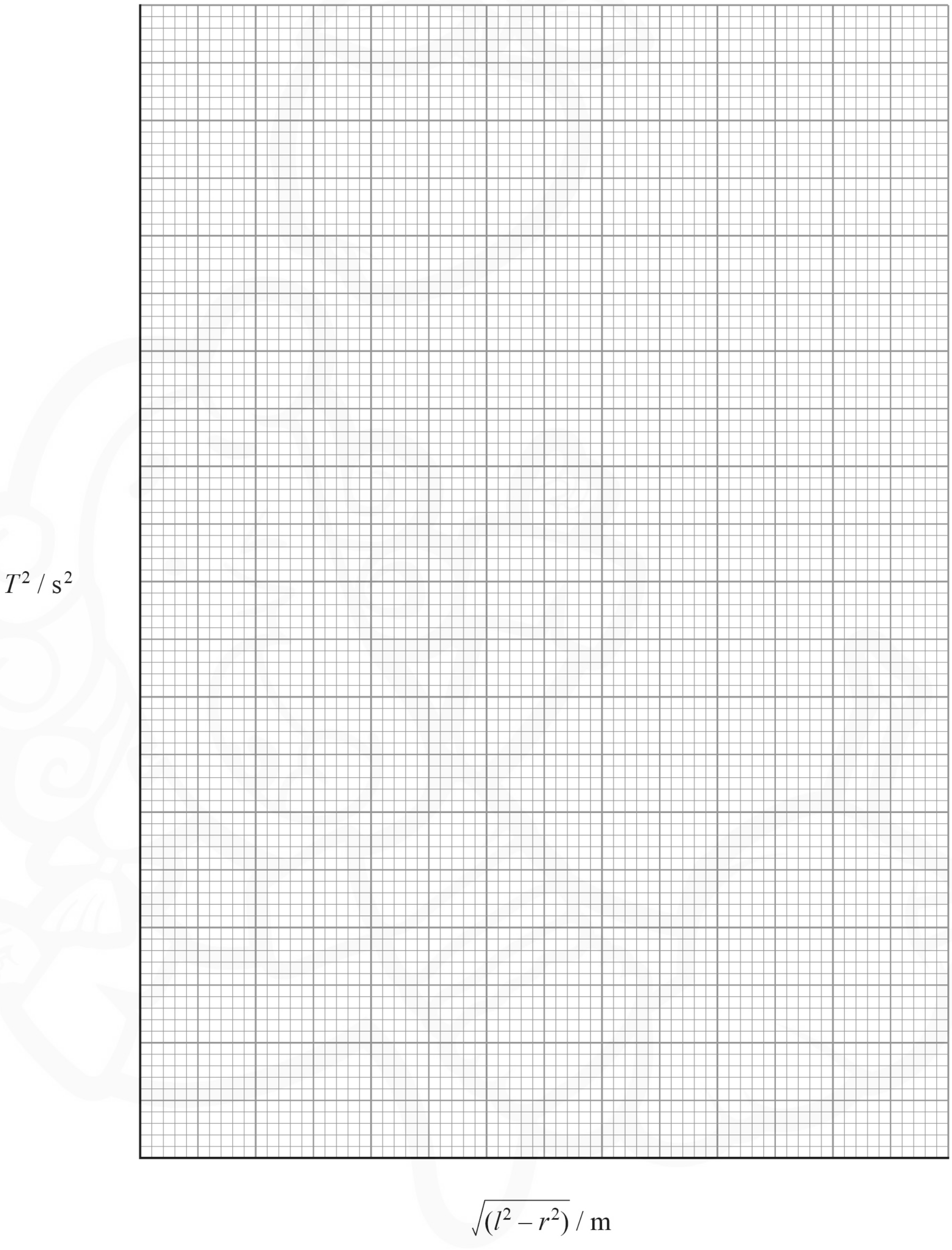
Draw, on **Figure 7**, a graph of T^2 against $\sqrt{(l^2 - r^2)}$.

Use false origins on both axes.

[4 marks]

Figure 7



Question 4 continues on the next page

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0 4 . 3 Determine the gradient of the graph you have drawn on **Figure 7**.

[2 marks]

gradient = ____________________

0 4 . 4 A student suggests that the relationship between T and l is given by

$$T^2 = \frac{4\pi^2}{k}\sqrt{\left(l^2 - r^2\right)}$$

Determine k.

[2 marks]

$k =$ ____________________ m s^{-2}

0 4 . 5 Determine whether or not the graph supports the idea that T^2 is directly proportional to $\sqrt{l^2 - r^2}$.

[2 marks]

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END OF SECTION A

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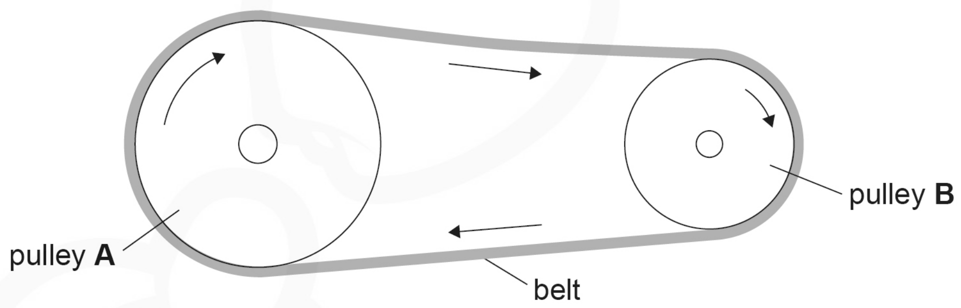
Section B

Answer **all** questions in this section.

0 5 **Figure 8** shows a belt-and-pulley system used by a car engine to drive an electrical generator.
The engine makes pulley **A** rotate and moves the belt.
The moving belt rotates pulley **B**. This drives the generator which is attached to **B**.

Figure 8



The car engine delivers a mean power of 930 W to the belt-and-pulley system.
Assume that the belt-and-pulley system is perfectly efficient.

0 5 . 1 The generator has an efficiency of 83%.
The generator has an rms output of 14 V.

Calculate the rms output current of the generator.

[3 marks]

rms output current = ____________________ A

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0 5 . 2 The belt does not slip on the pulleys. The angular speed of pulley **B** is $480\ \text{rad s}^{-1}$.
The diameter of pulley **A** is $22\ \text{cm}$.
The diameter of pulley **B** is $12\ \text{cm}$.

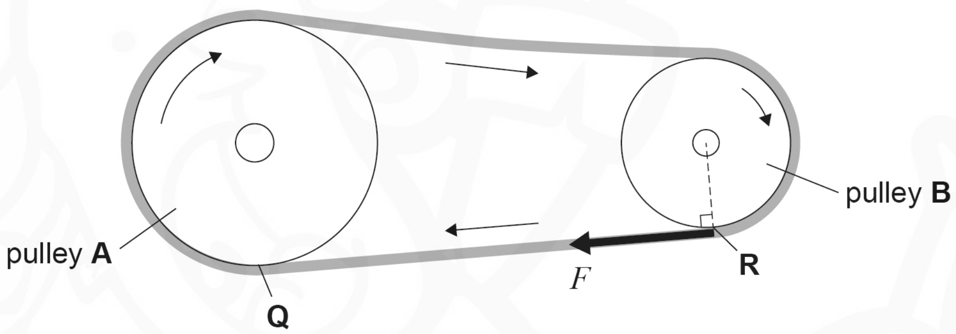
Calculate, in revolutions per minute, the frequency of rotation of pulley **A**.

[3 marks]

frequency of rotation = ______________________ revolutions per minute

The tension F in the belt acts on pulley **B** at point **R** in the direction shown in **Figure 9**.

Figure 9



0 5 . 3 F exerts a torque on pulley **B**. The power delivered to pulley **B** is $930\ \text{W}$.

Calculate F.

[3 marks]

F = ______________________ N

Question 5 continues on the next page

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0 5 . 4 The length of belt between **Q** and **R** is $0.25\ \text{m}$ when the system is at rest and there is no tension in the belt.

Pulley **A** is made to rotate more quickly.
The tension in the belt between **Q** and **R** is now $55\ \text{N}$.
The belt between **Q** and **R** has an extension of $1.0\ \text{mm}$ compared with its unstretched length.
The Young modulus of the belt material is $340\ \text{MPa}$.

Calculate the cross-sectional area of the belt.

[3 marks]

cross-sectional area = ____________________ m^2

0 5 . 5 After the belt has been used for a long time, it becomes permanently stretched and slips on the pulleys.

Explain how the performance of the whole system is affected by this slipping.

[2 marks]

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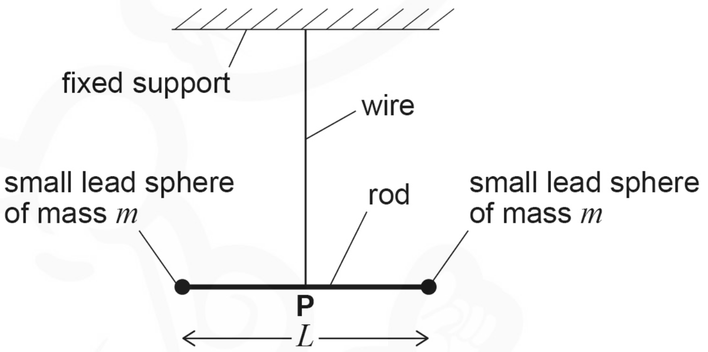
0 6 This question is about an attempt in 1798 to calculate the average density of the Earth.

Figure 10 shows a uniform rod, of negligible mass, suspended by a vertical wire from a fixed support.
Two small lead spheres are attached to the rod, one at each end. Each sphere acts as a point mass.
The mass m of each sphere is $0.730\ \text{kg}$.

P is the centre of the rod and the distance from **P** to each sphere is $\frac{L}{2}$.

The moment of inertia I of the spheres about **P** is $1.26\ \text{kg m}^2$.

Figure 10



0 6 . 1 Show that L is approximately $1.9\ \text{m}$.

[3 marks]

Question 6 continues on the next page

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Figure 11 shows the rod viewed from above. The vertical wire is not shown.

The rod is turned through a small angle θ. This causes the vertical wire to twist and exert a torque on the rod.

Figure 11

When the rod is released it performs oscillations about **P** in a horizontal plane.

The frequency f of the oscillations is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{I}}$$

where k is a constant.

0 6 . 2 The time period of the oscillation is 424 s.

Suggest why this period is difficult to measure.

[2 marks]

0 6 . 3 Show that k is approximately 2.8×10^{-4} N m rad^{-1}.

[2 marks]

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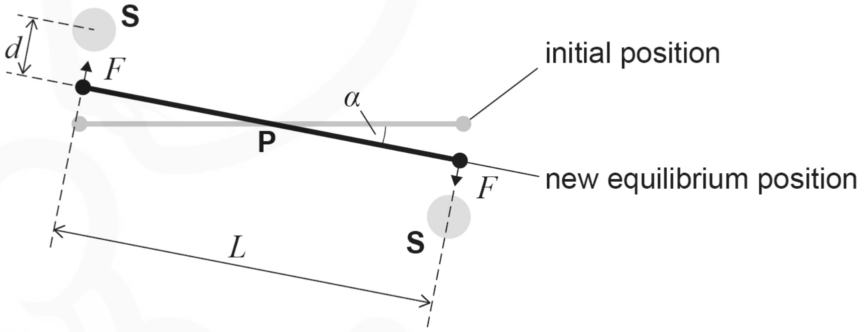
The rod returns to rest at its equilibrium position.
A large lead sphere **S** of mass M is placed near each small sphere.
Gravitational forces F act between each **S** and its nearest small sphere, producing a torque on the rod. This twists the wire, leading to a torque T in the wire.
The rod turns horizontally through an angle α to reach a new equilibrium position.
The torque now exerted by the forces F is equal and opposite to T.
The rod does not oscillate.

Figure 12 shows the equilibrium position viewed from above.

Figure 12



At equilibrium, the distance between the centre of each **S** and the centre of its nearest small sphere is d.

0 6 . 4 Show that the gravitational constant G is given by:

$$G = \frac{Td^2}{MmL}$$

[2 marks]

Question 6 continues on the next page

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At equilibrium, T is given by:

$$T = k\alpha$$

0 6 . 5 In one experiment:

$M = 158$ kg
$m = 0.730$ kg
$d = 0.225$ m
$k = 2.8 \times 10^{-4}$ N m rad^{-1}
$\alpha = 9.30 \times 10^{-4}$ rad
$L = 1.90$ m.

Show that these data suggest a value for G of approximately 6×10^{-11} N m^2 kg^{-2}.

[2 marks]

0 6 . 6 Calculate, using the value for G in Question **06.5**, the average density of the Earth.

$g = 9.81$ N kg^{-1}

[3 marks]

average density of the Earth = ______________________ kg m^{-3}

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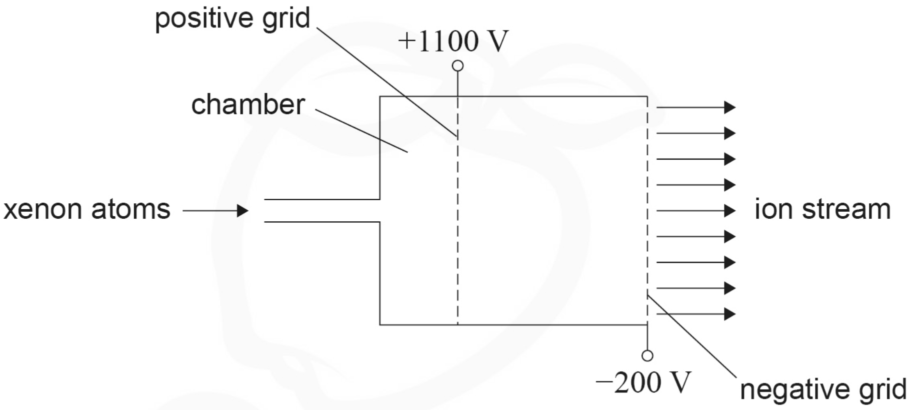
0 7 An ion drive is attached to a satellite and provides thrust to make small changes to the satellite's velocity. **Figure 13** shows the main features of the ion drive.

Figure 13



Xenon-131 atoms enter the chamber with negligible speed and pass through a positive grid. At the positive grid, a single electron is removed from each atom to form a xenon ion.

The positive grid is at a potential of +1100 V and the negative grid is at a potential of –200 V. The ions are accelerated through this potential difference.

A stream of ions is then ejected at high speed through the negative grid into space.

0 7 . 1 Explain why the ejection of a stream of ions in one direction causes the ion drive to accelerate in the opposite direction.

[3 marks]

Question 7 continues on the next page

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0 7 . 2 Show that the speed of the ions relative to the negative grid as they pass through it is approximately 44 km s^{-1}.

mass of xenon-131 ion $= 2.18 \times 10^{-25}$ kg

[2 marks]

0 7 . 3 The ion drive produces a thrust of 0.049 N.

Calculate the mass of xenon ejected through the negative grid each second.

[1 mark]

mass ejected each second = ____________________ kg

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One type of power supply used for ion drives is a radioisotope thermoelectric generator (RTG).

One RTG initially contains $7.80\ \text{kg}$ of plutonium-238 that decays by alpha emission. The decay energy is $5.69\ \text{MeV}$ and the decay constant is $2.50 \times 10^{-10}\ \text{s}^{-1}$.

0 7 . 4 Explain why energy is released when plutonium-238 decays.

[2 marks]

0 7 . 5 Show that the RTG contains approximately 2.0×10^{25} nuclei of plutonium-238.

[2 marks]

Question 7 continues on the next page

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0 7 . 6 When 1.0 J of energy is transferred through nuclear decay, the RTG transfers 68 mJ into electrical energy.
The ion drive requires a power of approximately 1.0 kW.

Determine whether or not the RTG is able to deliver this power.

[4 marks]

0 7 . 7 Another type of RTG uses 7.80 kg of strontium-90 instead of plutonium-238.
This strontium-based RTG has the same efficiency as the plutonium-based RTG.
Strontium-90 has a decay constant of $7.63 \times 10^{-10}\ \text{s}^{-1}$ and a decay energy of 0.546 MeV.

Suggest how this change of fuel type affects the performance of the RTG.

[2 marks]

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