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Centre number

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Candidate number

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Surname StemUp Model Solution

Forename(s) _____

Candidate signature _____

I declare this is my own work.

INTERNATIONAL A-LEVEL PHYSICS

Unit 5 Physics in practice

Wednesday 27 January 2021

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	



J A N 2 1 P H 0 5 0 1

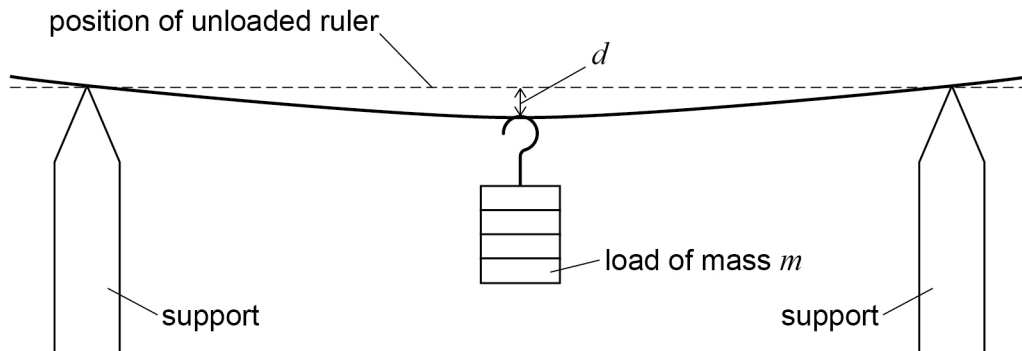
Section A

Answer **all** questions in this section.

0 1

Figure 1 shows a ruler resting on two supports. A load of mass m is suspended from the centre of the ruler.

The deflection d of the centre of the ruler is measured.

Figure 1

0 1 . 1

The deflection d is found for a range of values of m . These data are plotted on **Figure 2** including error bars for the values of d . The line of maximum gradient $\mu_{\max}$ consistent with the data is also shown.

Draw, on **Figure 2**, the line of minimum gradient consistent with the data.

[1 mark]

0 1 . 2

Determine the gradient $\mu_{\min}$ of the line that you have drawn in Question 01.1.

[2 marks]

Large triangle drawn on my line of minimum gradient (Figure 2):

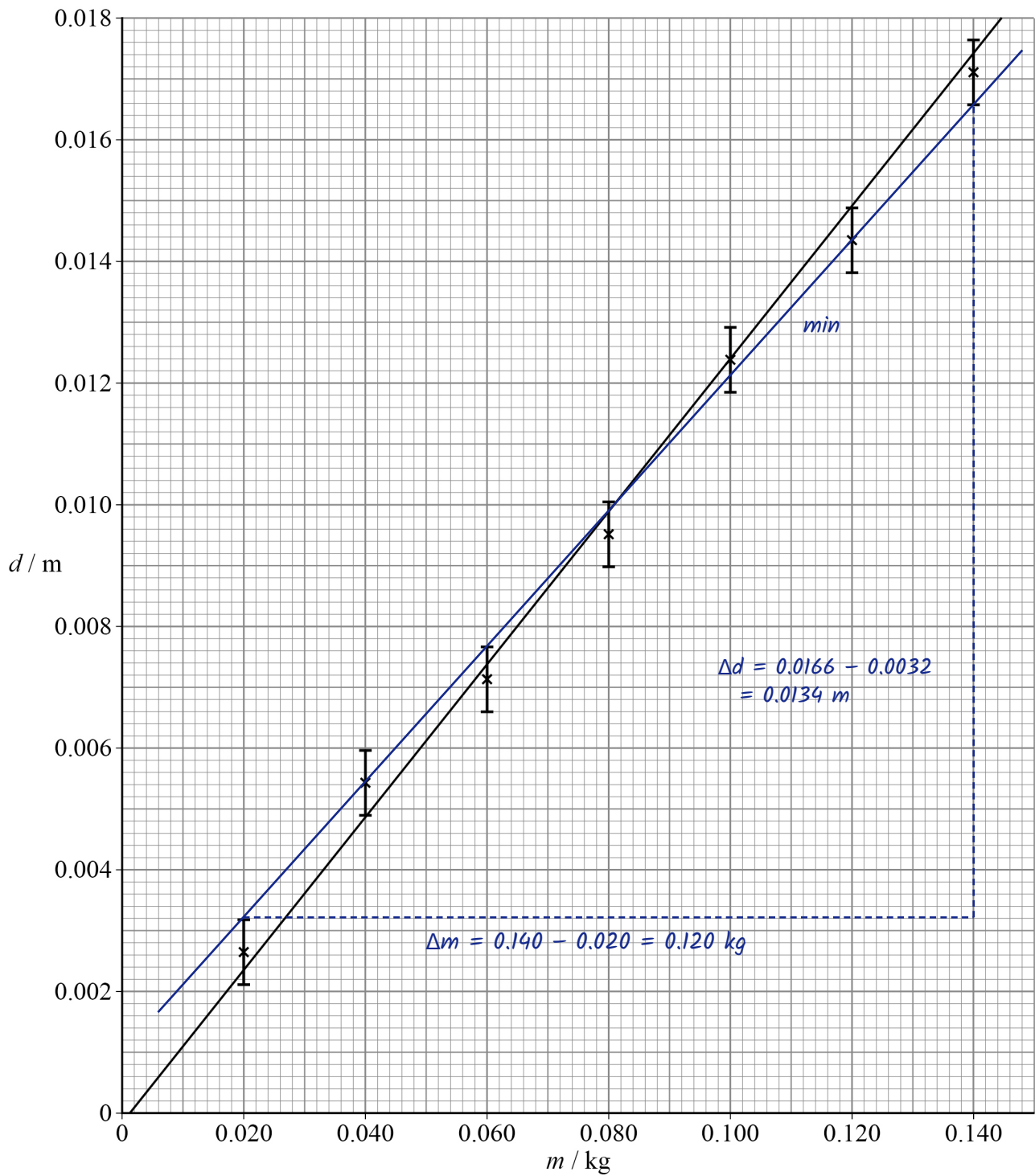
$$\mu_{\min} = \Delta d / \Delta m = (0.0166 - 0.0032) / (0.140 - 0.020)$$

$$= 0.0134 / 0.120 = 0.112 \text{ m kg}^{-1}$$

$$\mu_{\min} = \underline{0.112} \text{ m kg}^{-1}$$



Figure 2



Question 1 continues on the next page

Turn over ►



0 1 . 3

The gradient $\mu_{\max}$ shown in **Figure 2** is 0.126 m kg^{-1} .

Estimate μ , the value of the best gradient of the graph in **Figure 2**.

[1 mark]

$$\mu = (\mu_{\max} + \mu_{\min}) / 2 = (0.126 + 0.112) / 2$$

$$\mu = \underline{0.119} \text{ m kg}^{-1}$$

0 1 . 4

Estimate the percentage uncertainty in μ .

[2 marks]

$$\text{uncertainty in } \mu = \text{half the range} = (0.126 - 0.112) / 2 = 0.007 \text{ m kg}^{-1}$$

$$\text{percentage uncertainty} = (0.007 / 0.119) \times 100$$

$$\text{percentage uncertainty in } \mu = \pm \underline{5.9 \%}$$



0 1 . 5

The amount that the ruler deforms depends on the Young modulus E of the ruler material and other properties of the ruler.

It can be shown that $E = \frac{k}{\mu}$ where k is a constant.

For this ruler, $k = 1.79 \times 10^9 \text{ s}^{-2}$.

Calculate E .

[1 mark]

$$E = k / \mu = 1.79 \times 10^9 / 0.119 = 1.50 \times 10^{10} \text{ Pa}$$

$$E = \underline{1.50 \times 10^{10}} \text{ Pa}$$

0 1 . 6

The uncertainty in k is negligible.

Calculate the absolute uncertainty in E .

[1 mark]

$$\text{percentage uncertainty in } E = \text{percentage uncertainty in } \mu = 5.9 \%$$

$$\text{absolute uncertainty} = 0.059 \times 1.50 \times 10^{10}$$

$$\text{absolute uncertainty in } E = \pm \underline{8.9 \times 10^8} \text{ Pa}$$

8

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ANSWER IN THE SPACES PROVIDED**

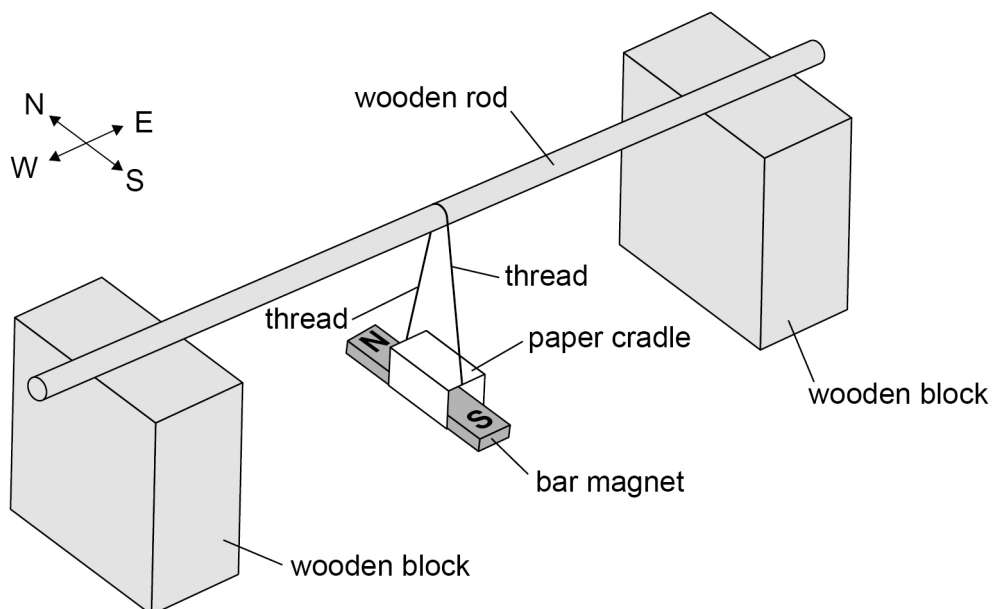


0 2

Figure 3 shows apparatus used to investigate the oscillations of a bar magnet. The magnet is held in a paper cradle. The paper cradle is suspended horizontally by threads from a wooden rod.

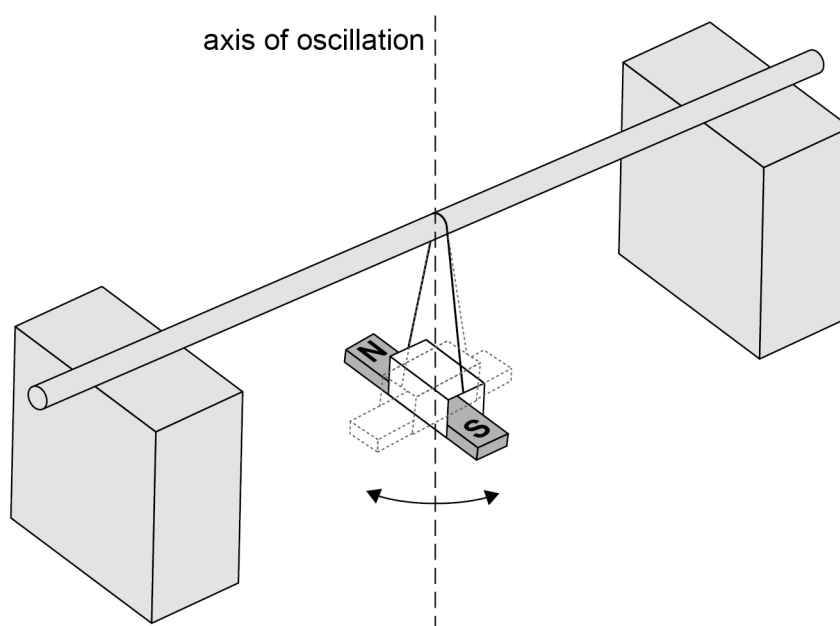
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Figure 3



Initially, the magnet is at rest parallel to the horizontal component of the Earth's magnetic field with its N pole towards the north. The magnet is displaced and released so that it oscillates about a vertical axis through its centre, as shown in **Figure 4**.

Figure 4



Question 2 continues on the next page

Turn over ►



0 2 . 1

The time T for one oscillation is determined five times.
The values for T are shown in **Table 1**.

Table 1

T / s	1.07	1.04	1.01	1.03	1.05
----------------	------	------	------	------	------

Calculate T_N , the mean value of T .

[1 mark]

$$T_N = (1.07 + 1.04 + 1.01 + 1.03 + 1.05) / 5 = 5.20 / 5$$

$$T_N = \underline{1.04} \text{ s}$$

0 2 . 2

Calculate a value for the absolute uncertainty in T_N .

[1 mark]

$$\text{half the range} = (1.07 - 1.01) / 2 = 0.03 \text{ s}$$

$$\text{absolute uncertainty in } T_N = \pm \underline{0.03} \text{ s}$$

0 2 . 3

State and explain how a fiducial marker and a stopwatch can be used to make an accurate determination of T_N .

[3 marks]

Place a fiducial marker (e.g. a vertical pin or line) at the centre of the oscillation, at the rest position of the magnet, because the magnet moves fastest there so the instant it passes can be judged most precisely.

Time at least 10 oscillations in one timing with the stopwatch, starting and stopping as the magnet passes the marker in the same direction, then divide by 10. This reduces the percentage uncertainty from reaction time.

Repeat the timing several times and calculate the mean T_N .



0 2 . 4

Calculate the percentage uncertainty in f_N^2 , the mean frequency of the oscillations.**[2 marks]**

$$f_N = 1/T_N, \text{ so \% uncertainty in } f_N = \% \text{ uncertainty in } T_N$$

$$= (0.03 / 1.04) \times 100 = 2.9 \%$$

$$f_N^2: \% \text{ uncertainty} = 2 \times 2.9$$

$$\text{percentage uncertainty in } f_N^2 = \underline{\quad 5.8 \% \quad}$$

In a second experiment, the bar magnet is positioned horizontally with the S pole pointing north. The same procedure is then followed to determine the mean time T_S for one oscillation.

Theory predicts that

$$f_N^2 - f_S^2 = k B_H$$

where

f_S is the frequency of the oscillations in the second experiment

B_H is the horizontal component of the Earth's magnetic flux density

k is a constant for the system.

0 2 . 5

Calculate a value for k .

State your answer to an appropriate number of significant figures.

State an appropriate unit for your answer.

$$B_H = 2.1 \times 10^{-5} \text{ T}$$

$$T_S = 1.39 \text{ s}$$

[3 marks]

$$k = (f_N^2 - f_S^2) / B_H = (1/1.04^2 - 1/1.39^2) / 2.1 \times 10^{-5}$$

$$= (0.925 - 0.518) / 2.1 \times 10^{-5} = 0.407 / 2.1 \times 10^{-5}$$

$$= 1.94 \times 10^4$$

$$k = \underline{\quad 1.9 \times 10^4 \quad}$$

$$\text{unit} = \underline{\quad \text{Hz}^2 \text{ T}^{-1} \quad (\text{s}^{-2} \text{ T}^{-1}) \quad}$$

10

Turn over ►



0 3

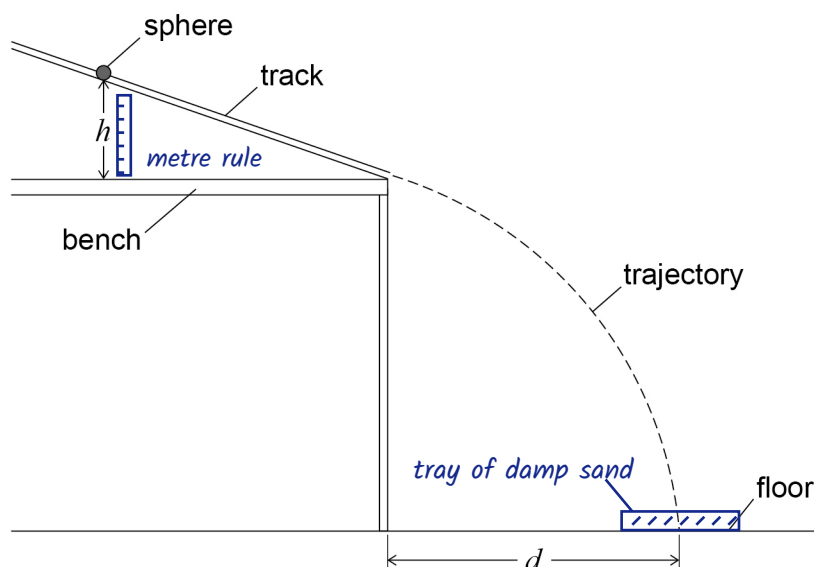
Figure 5 shows the apparatus used to investigate the motion of a small solid sphere.

The sphere, of mass m , is released from rest. It rolls, without slipping, down an inclined track through a vertical distance h .

As the sphere leaves the track it has a linear velocity v and an angular speed ω .

The sphere then falls freely. It hits the floor a horizontal distance d from the end of the track.

Figure 5



0 3 . 1

The principle of conservation of energy suggests that

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

The moment of inertia of the sphere $I = \frac{2}{5}mr^2$ where r is the radius of the sphere.

Show that $v = \sqrt{\frac{10gh}{7}}$

[2 marks]

$$I = (2/5)mr^2 \text{ and } \omega = v/r, \text{ so } \frac{1}{2}I\omega^2 = \frac{1}{2} \times (2/5)mr^2 \times v^2/r^2 = (1/5)mv^2$$

$$mgh = \frac{1}{2}mv^2 + (1/5)mv^2 = (5/10 + 2/10)mv^2 = (7/10)mv^2$$

$$gh = (7/10)v^2 \text{ so } v^2 = 10gh / 7 \text{ so } v = \sqrt{10gh / 7}$$



0 3 . 2

A student suggests that d is directly proportional to h .

Describe an experiment, using the apparatus in **Figure 5**, to test this suggestion.

Your answer should include details of:

- any other apparatus required
- the measurements required
- the procedure needed to find accurate values for d
- the analysis of the data.

You may add to **Figure 5** to support your answer.

[5 marks]

Apparatus: a metre rule (with a set square) to measure the vertical height h from the release point to the end of the track, and a tray of damp sand (or carbon paper on white paper) on the floor where the sphere lands, so the impact point is marked. A plumb line from the end of the track marks the point on the floor from which d is measured with a metre rule.

Procedure: release the sphere from rest (do not push it) at a marked point on the track and measure h . Measure d from the plumb line point to the centre of the mark in the sand.

Repeat each release three times and calculate the mean d for each h , discarding anomalies.

Use at least six different values of h , spread along the full length of the track.

Analysis: plot a graph of mean d (y-axis) against h (x-axis). If d is directly proportional to h the graph is a straight line through the origin.

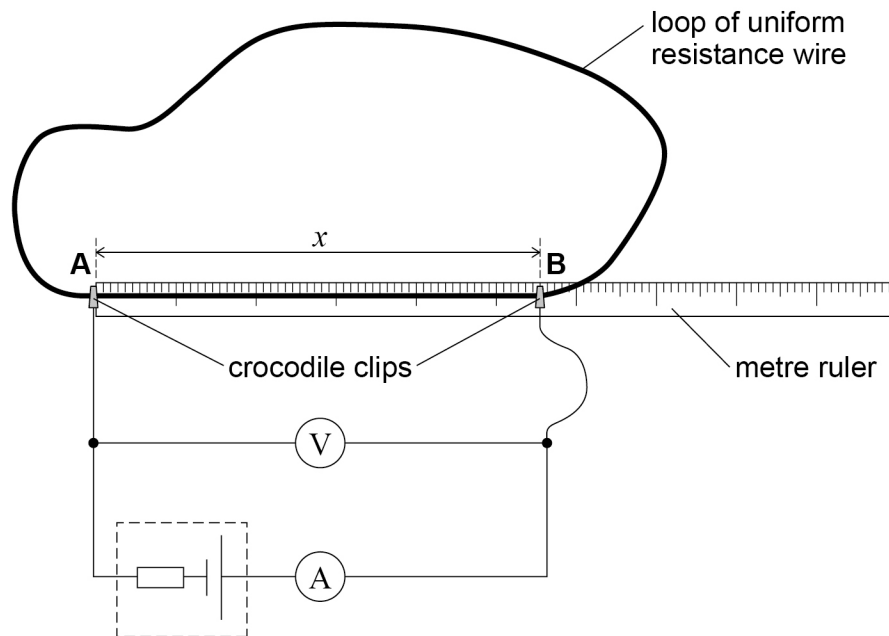
7

Turn over ►



0 4

Figure 6 shows a continuous loop of uniform resistance wire connected into a circuit. Crocodile clips **A** and **B** are connected to points on the loop. The straight-line distance x between **A** and **B** is measured using a metre ruler. The total length of wire in the loop is L .

Figure 6

The current I in the cell is measured using an ammeter.
The potential difference V between **A** and **B** is measured using a voltmeter.
 V and I are both measured for a range of values of x .

Table 2 shows data from the experiment.

Table 2

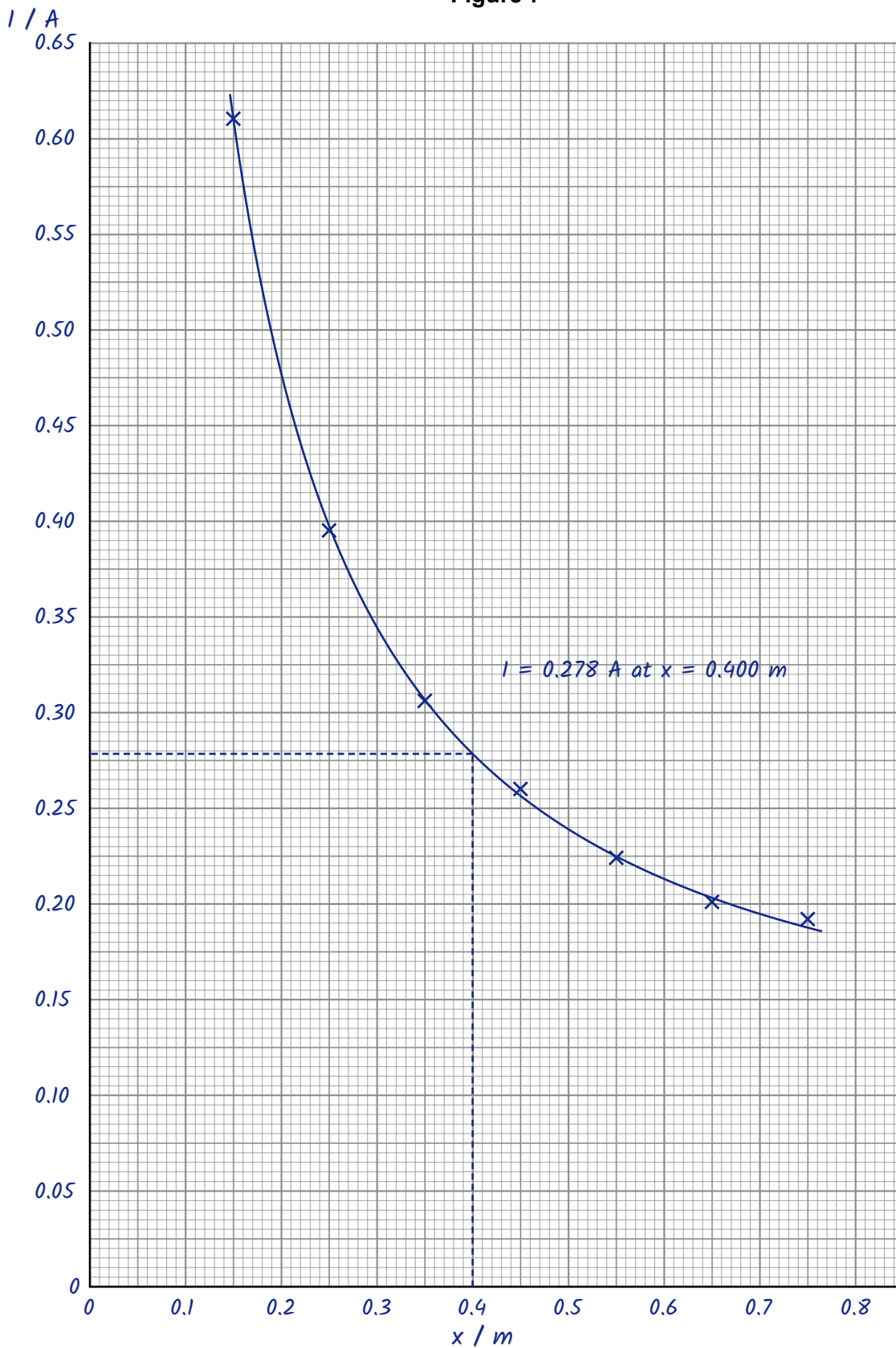
x / m	V / V	I / A
0.150	1.37	0.610
0.250	1.43	0.395
0.350	1.46	0.306
0.450	1.48	0.260
0.550	1.49	0.224
0.650	1.50	0.201
0.750	1.50	0.192



0 4 . 1 Draw, on **Figure 7**, a graph of I against x .

[5 marks]

Figure 7



Question 4 continues on the next page

Turn over ►



0 4 . 2

Determine, using **Figure 7**, a value for I when $x = 0.400$ m.
Show your working on **Figure 7**.

[1 mark]

$$I = \underline{\hspace{2cm} 0.278 \hspace{2cm}} \text{ A}$$

0 4 . 3

Theory predicts that

$$I = \frac{LV}{k(Lx - x^2)}$$

For the data shown in **Table 2**, L is 2.2 m.

Determine, for $x = 0.400$ m, a value for k .
State an appropriate unit for k .

[3 marks]

At $x = 0.400$ m, $V = 1.47$ V (between 1.46 V and 1.48 V in Table 2)

and $I = 0.278$ A (from Figure 7)

$$k = LV / I(Lx - x^2)$$

$$k = (2.2 \times 1.47) / (0.278 \times (2.2 \times 0.400 - 0.400^2))$$

$$= 3.234 / (0.278 \times 0.720) = 3.234 / 0.2002$$

$$= 16.2 \, \Omega \, \text{m}^{-1}$$

$$k = \underline{\hspace{2cm} 16.2 \hspace{2cm}}$$

$$\text{unit} = \underline{\hspace{2cm} \Omega \, \text{m}^{-1} \hspace{2cm}}$$



0 4 . 4

Explain why V increases as x increases for the range of data in **Table 2**.**[2 marks]**

*As x increases, the resistance of the loop between A and B increases,
so the total resistance increases and the current I in the cell decreases.
So the p.d. lost across the internal resistance of the cell (Ir) decreases,
and the terminal p.d. $V = \varepsilon - Ir$ increases.*

11

END OF SECTION A**Turn over ►**

Section BAnswer **all** questions in this section.**0 5**

This question is about comparing the surface conditions on Earth with those on K2-18b, a recently discovered planet.

K2-18b orbits the star K2-18. K2-18 is a distance D from Earth.

Table 3 shows data for the planets Earth and K2-18b.

Table 3

	Earth	K2-18b
Mass of planet / kg	5.98×10^{24}	5.33×10^{25}
Radius of planet / m	6.37×10^6	1.43×10^7
Orbital radius of planet / m	1.50×10^{11}	2.14×10^{10}

0 5 . 1

Show that the gravitational field strength g_k at the surface of K2-18b is given by

$$g_k = \left(\frac{R_E}{R_K} \right)^2 \left(\frac{M_K}{M_E} \right) g_E$$

where

g_E is the gravitational field strength at the surface of the Earth

R_E is the radius of the Earth

R_K is the radius of K2-18b

M_E is the mass of the Earth

M_K is the mass of K2-18b.

[2 marks]

$$g = GM / R^2 \text{ for each planet: } g_k = GM_K / R_K^2 \text{ and } g_E = GM_E / R_E^2$$

$$\text{dividing: } g_k / g_E = (GM_K / R_K^2) \times (R_E^2 / GM_E) = (R_E^2 / R_K^2) \times (M_K / M_E)$$

$$\text{so } g_k = (R_E / R_K)^2 (M_K / M_E) g_E$$



0 5 . 2 Calculate g_k .

[1 mark]

$$g_k = (6.37 \times 10^6 / 1.43 \times 10^7)^2 \times (5.33 \times 10^{25} / 5.98 \times 10^{24}) \times 9.81$$

$$= 0.198 \times 8.91 \times 9.81$$

$$g_k = \underline{17.4} \text{ N kg}^{-1}$$

0 5 . 3 Calculate, in Earth days, the orbital period for K2-18b.

[3 marks]

$$\text{mass of the star K2-18} = 8.22 \times 10^{29} \text{ kg}$$

gravitational force provides centripetal force:

$$GMm / r^2 = mr\omega^2 \quad \text{so} \quad \omega = \sqrt{GM / r^3}$$

$$\omega = \sqrt{(6.67 \times 10^{-11} \times 8.22 \times 10^{29} / (2.14 \times 10^{10})^3)}$$

$$\omega = \sqrt{(5.48 \times 10^{19} / 9.80 \times 10^{30})} = 2.37 \times 10^{-6} \text{ rad s}^{-1}$$

$$T = 2\pi / \omega = 2.66 \times 10^6 \text{ s}$$

$$T = 2.66 \times 10^6 / (3600 \times 24)$$

$$= 30.7 \text{ days}$$

$$\text{orbital period for K2-18b} = \underline{30.7} \text{ Earth days}$$

Question 5 continues on the next page

Turn over ►



Table 4 shows data for the two stars: the Sun and K2-18.

Table 4

	Sun	K2-18
Radius of star / m	6.96×10^8	3.26×10^8
Power output of star / W	3.85×10^{26}	9.01×10^{24}

0 5 . 4

Compare the intensity of the radiation received by planet K2-18b from its star K2-18 with the intensity of the solar radiation received by the Earth from the Sun.

[3 marks]

Intensity $I = P / 4\pi r^2$, using the orbital radius of each planet:

$$\text{Earth: } I_E = 3.85 \times 10^{26} / (4\pi \times (1.50 \times 10^{11})^2) = 1360 \text{ W m}^{-2}$$

$$\text{K2-18b: } I_K = 9.01 \times 10^{24} / (4\pi \times (2.14 \times 10^{10})^2) = 1570 \text{ W m}^{-2}$$

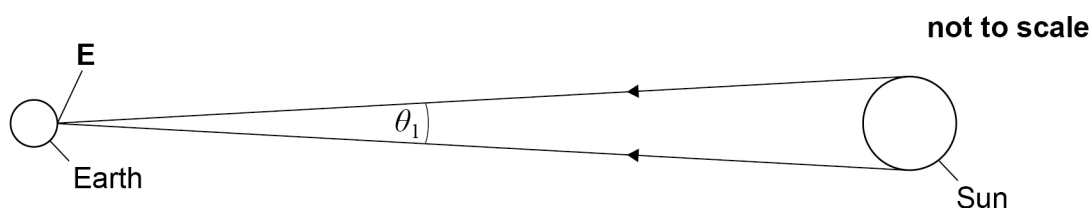
$$I_K / I_E = 1570 / 1360 = 1.15$$

The intensities are comparable: K2-18b receives about 1.15 times the intensity the Earth receives.



0 5 . 5

Figure 8 shows two rays of light from the Sun arriving at a point **E** on Earth. The Sun subtends an angle of θ_1 at point **E**.

Figure 8

θ_2 is the angle subtended at point **E** on Earth by the star K2-18.

$$\frac{\theta_1}{\theta_2} = 1.67 \times 10^7$$

Calculate the distance D between the Earth and star K2-18.

[3 marks]

$$\theta_1 = \text{arc length} / \text{radius} = 2 \times 6.96 \times 10^8 / 1.50 \times 10^{11} = 9.28 \times 10^{-3} \text{ rad}$$

$$\theta_2 = \theta_1 / 1.67 \times 10^7 = 5.56 \times 10^{-10} \text{ rad}$$

$$D = 2 \times 3.26 \times 10^8 / 5.56 \times 10^{-10}$$

$$D = \underline{1.17 \times 10^{18}} \text{ m}$$

0 5 . 6

Light from K2-18 passes through the atmosphere of K2-18b. This light is detected and analysed when it arrives at the Earth.

State how the wavelengths present in this light can be determined.

Go on to explain how this gives information about the elements present in the atmosphere of K2-18b.

[2 marks]

Pass the light through a diffraction grating (spectrometer) and measure

the angles of the lines: the wavelengths follow from $d \sin \theta = n\lambda$.

Atoms of each element absorb photons only at wavelengths matching

the differences between their energy levels, so the dark absorption lines

form a characteristic line spectrum that identifies the elements.

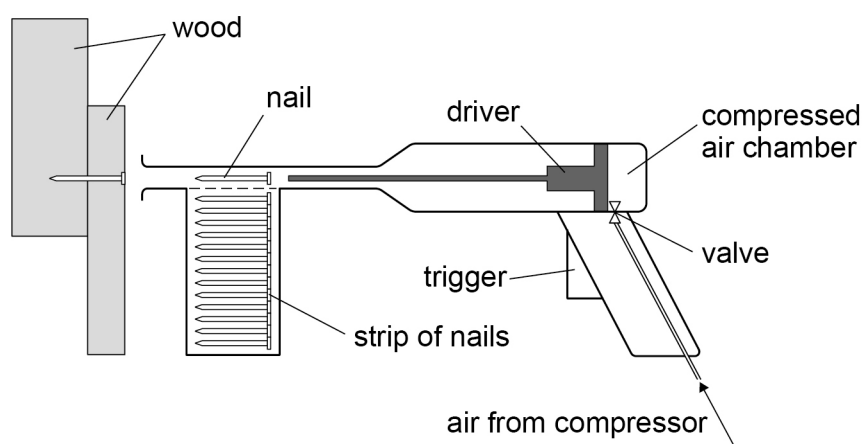


0 6

Nailers are designed to force nails into wood.

Figure 9 shows the main parts of a nailer that is operated by compressed air.

Figure 9



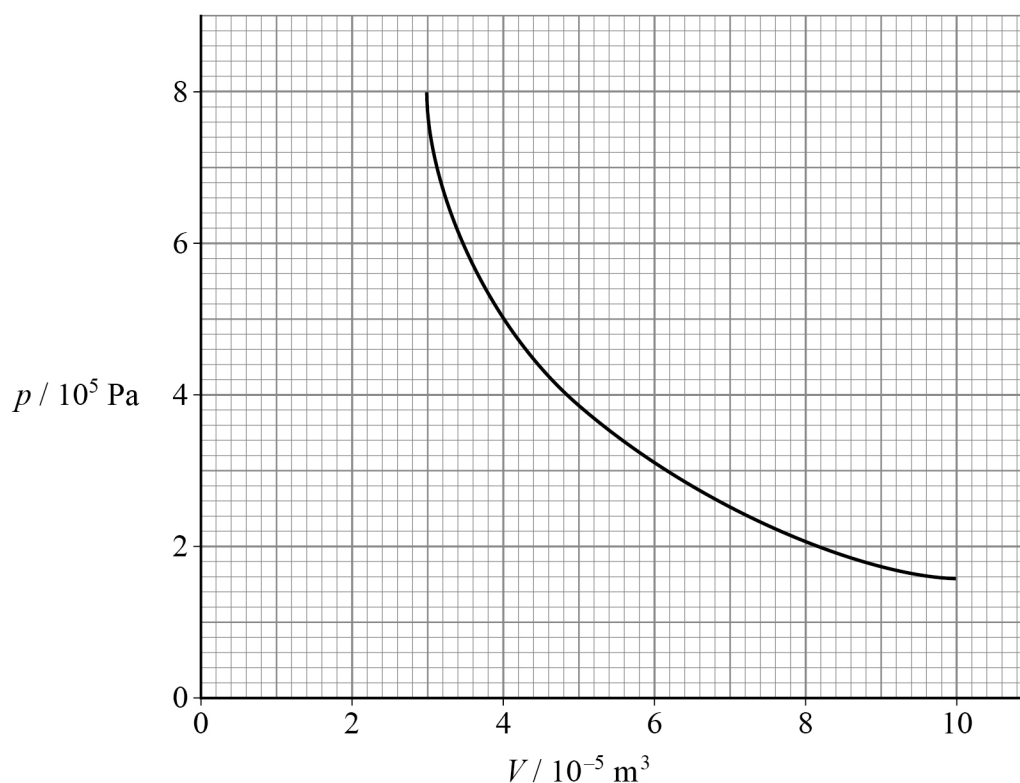
9.8×10^{-3} mol of air is fed into the compressed air chamber through a valve. The valve then closes.

The air is now at a temperature of 295 K and a pressure of 8.0×10^5 Pa.

When the trigger is pressed, this air expands rapidly, pushing the driver forward. The driver hits the nail, breaking it free from the strip and forcing the nail into the wood.

Figure 10 is a p - V diagram for the compressed air as it expands.

Figure 10



0 6 . 1

Show that the energy available to the driver as the compressed air expands is approximately 23 J.

[3 marks]

Energy (work done by the gas) = area under the p-V curve

one large square = $1 \times 10^5 \text{ Pa} \times 1 \times 10^{-5} \text{ m}^3 = 1 \text{ J}$

counting squares under the curve from $V = 3$ to $10 \times 10^{-5} \text{ m}^3$:

about 23 large squares

energy $\approx 23 \times 1 \text{ J} = 23 \text{ J}$

0 6 . 2

Only 40% of the energy available from the expanding air is transferred to the nail. 1.9 J of the energy transferred to the nail is used to separate the nail from the strip. The nail is driven 3.5 cm into the wood.

Calculate the average resistance force of the wood on the nail.

[3 marks]

energy to nail = $0.40 \times 23 = 9.2 \text{ J}$

energy used in the wood = $9.2 - 1.9 = 7.3 \text{ J}$

work done = $F \times d$ so $F = 7.3 / 0.035$

= 209 N

average resistance force = 209 N

0 6 . 3

Calculate the temperature of the air just after it has expanded to a volume of $10 \times 10^{-5} \text{ m}^3$.

[2 marks]

$pV = nRT$; at $V = 10 \times 10^{-5} \text{ m}^3$, $p = 1.6 \times 10^5 \text{ Pa}$ (Figure 10)

$T = pV / nR = (1.6 \times 10^5 \times 10 \times 10^{-5}) / (9.8 \times 10^{-3} \times 8.31)$

= 196 K

temperature = 196 K

Question 6 continues on the next page

Turn over ►



0 6 . 4

The pressure of the air in the compressed air chamber decreases as its volume increases.

Explain this decrease, with reference to the kinetic theory model.

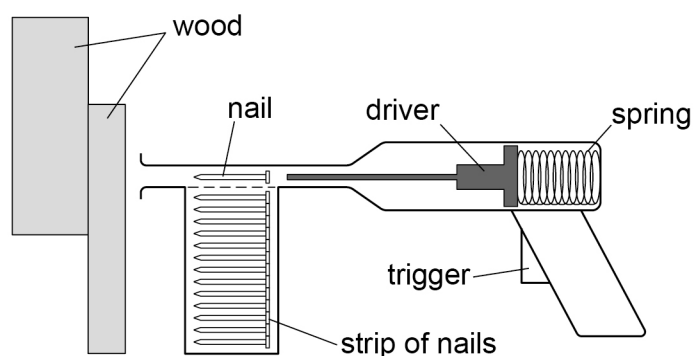
[2 marks]

The air does work as it expands, so its temperature falls and the molecules have a smaller mean (rms) speed; the volume is also larger, so there is a longer time between collisions of the molecules with the walls.

So the rate of change of momentum at the walls is smaller, giving a smaller force per unit area, so a lower pressure.

Figure 11 shows another type of nailer.
This nailer uses the energy stored in a compressed spring.

Figure 11



The spring stores an energy of 25 J when it is fully compressed.
When the trigger is pressed, the spring transfers this energy to the nail, forcing it into the wood.
An electric motor then automatically compresses the spring ready for the next nail.
The motor has a power output of 190 W. The motor is powered by an 18 V, 1.5 A h battery. The battery has negligible internal resistance.

0 6 . 5

Calculate the minimum time between one nail being delivered and the next.

[1 mark]

$$t = E / P = 25 / 190 = 0.132 \text{ s}$$

minimum time = 0.132 s



0 6 . 6

Estimate the number of nails that can be delivered using a freshly charged battery before it needs to be recharged.
Assume that the motor is 100% efficient.

[1 mark]

$$\text{energy stored in battery} = VQ = 18 \times 1.5 \times 3600 = 97\,200 \text{ J}$$

$$\text{number of nails} = 97\,200 / 25 = 3888$$

$$\text{number of nails} = \underline{3890}$$

12

Turn over for the next question

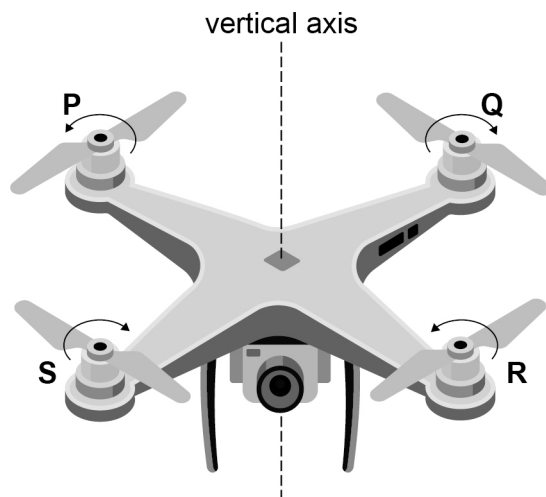
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0 7

Figure 12 shows a drone that has four motor-propeller units. Each propeller **P**, **Q**, **R** and **S** is driven by its own motor. The drone has a mass of 1.6 kg.

Figure 12



Initially, the drone hovers in one place at a constant height and does not rotate about its vertical axis.

0 7 . 1

Explain why it is necessary to have two propellers rotating clockwise and two propellers rotating anti-clockwise.

[2 marks]

Angular momentum is conserved; initially the drone has zero angular momentum about its vertical axis.

With two propellers clockwise and two anti-clockwise, the angular momenta of the propellers cancel so the total angular momentum of the propellers is zero, and the body of the drone does not rotate (the torques from the motors on the body cancel).



Figure 13 shows the variation of thrust F with current I for **one** motor-propeller unit up to its maximum current of 21 A.

Figure 13

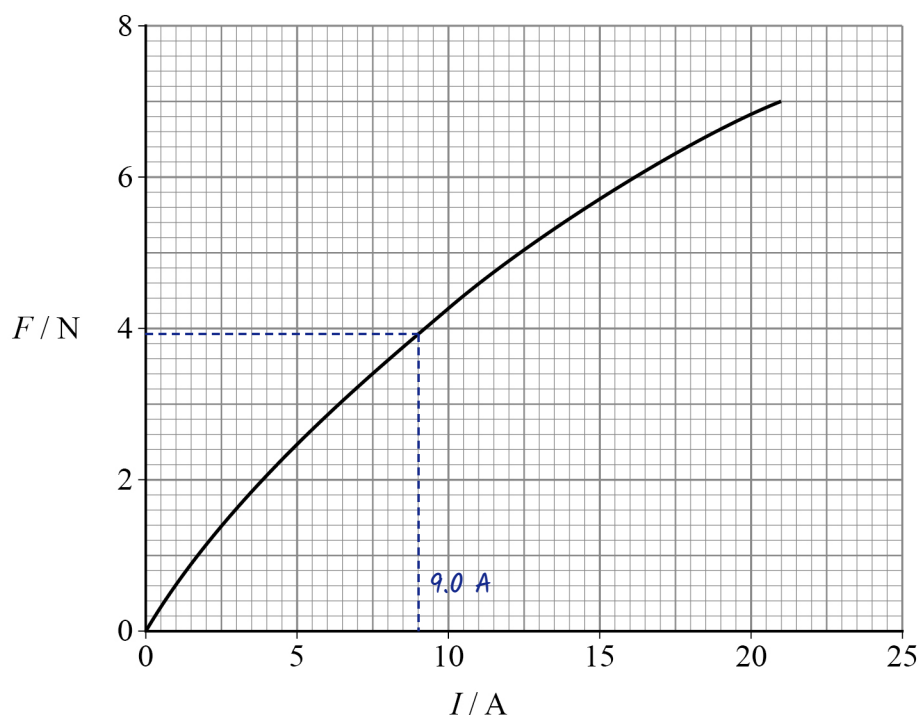
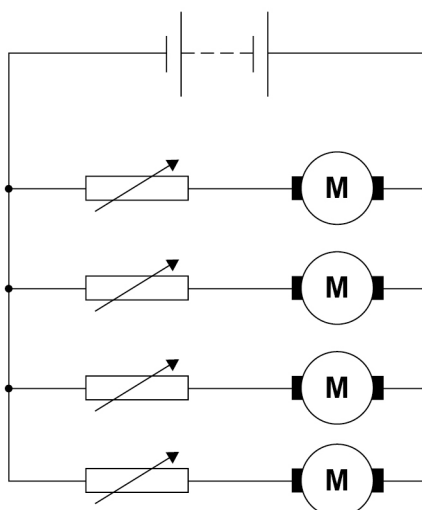


Figure 14 shows how each motor is connected in parallel with a 12 V battery. The current in each motor can be varied using a variable resistor.

Figure 14



Question 7 continues on the next page

Turn over ►



07.2

Show that F is approximately 4 N when the drone is hovering.

[1 mark]

$$\text{weight} = mg = 1.6 \times 9.81 = 15.7 \text{ N, shared between 4 propellers}$$

$$F = 15.7 / 4 = 3.92 \text{ N} \approx 4 \text{ N}$$

07.3

Determine the **total** power delivered by the battery when the drone is hovering. Assume that the internal resistance of the battery is negligible.

[3 marks]

$$\text{From Figure 13, } F = 3.9 \text{ N when } I = 9.0 \text{ A (for one motor)}$$

$$P = VI = 12 \times 9.0 = 108 \text{ W for one motor}$$

$$\text{total power} = 4 \times 108$$

$$= 432 \text{ W}$$

$$\text{total power} = \underline{\quad 432 \quad} \text{ W}$$

07.4

Explain how **Figure 13** shows that the internal resistance of the battery must be small.

[2 marks]

Figure 13 shows each motor takes up to 21 A, so the battery supplies a large current (up to 84 A).

With such a current the lost volts Ir are only small if r is small, so the terminal p.d. stays close to the 12 V emf and little power is wasted.



0 7 . 5

The drone operator now makes the drone climb through a height change of 200 m.

Calculate, using data from **Figure 13**, the minimum time required for this height change.

[4 marks]

$$\text{maximum thrust from Figure 13} = 7.0 \text{ N per motor (at 21 A)}$$

$$\text{total maximum thrust} = 4 \times 7.0 = 28 \text{ N}$$

$$\text{resultant force} = \text{thrust} - mg = 28 - 15.7 = 12.3 \text{ N}$$

$$a = F / m = 12.3 / 1.6 = 7.69 \text{ m s}^{-2}$$

$$\text{starting from rest: } s = \frac{1}{2}at^2$$

$$t = \sqrt{(2s / a)} = \sqrt{(2 \times 200 / 7.69)}$$

$$= 7.2 \text{ s}$$

minimum time = 7.2 s

Question 7 continues on the next page

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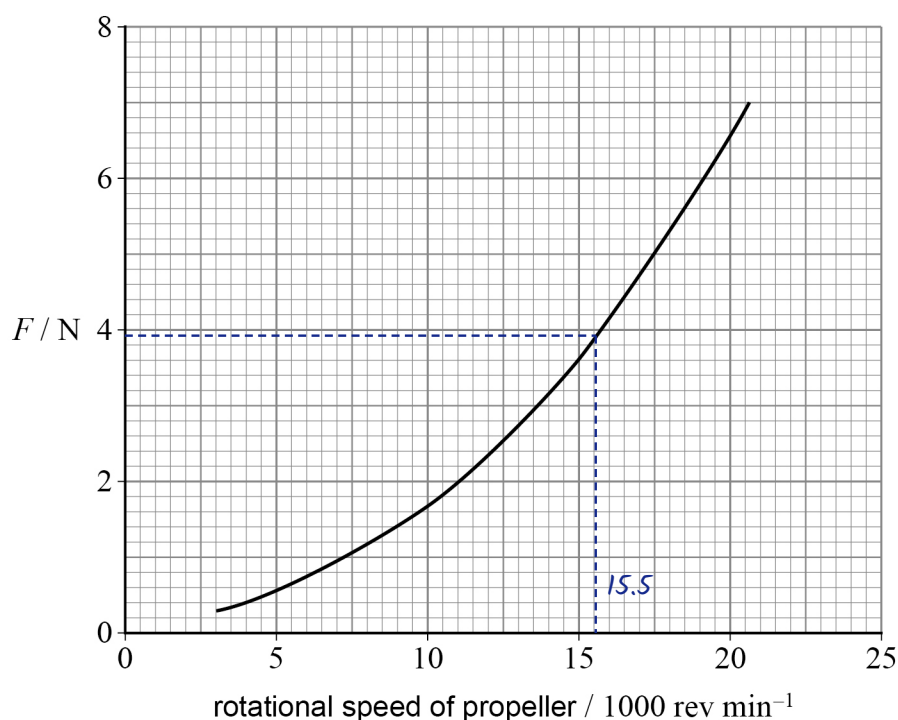


0 7 . 6

The operator makes the drone hover at its new height.

Figure 15 shows the variation of F with the rotational speed of one propeller.

Figure 15



Calculate, in rad s^{-1} , the angular speed of a propeller when the drone is hovering.

[2 marks]

$F = 3.92 \text{ N}$ when hovering: from Figure 15,

rotational speed = $15\,500 \text{ rev min}^{-1}$

$f = 15\,500 / 60 = 258 \text{ rev s}^{-1}$

$\omega = 2\pi f = 2\pi \times 258$

$= 1623 \text{ rad s}^{-1}$

angular speed of propeller = 1623 rad s^{-1}



0 7 . 7

The drone operator wants to rotate the drone about its vertical axis. To do this, the angular speeds of propellers **P** and **R** are decreased by 100 rad s^{-1} and the angular speeds of propellers **Q** and **S** are increased by 100 rad s^{-1} .

Calculate the angular speed gained by the drone.

$$\begin{aligned}\text{moment of inertia of the drone} &= 0.021 \text{ kg m}^2 \\ \text{moment of inertia of a propeller} &= 4.8 \times 10^{-5} \text{ kg m}^2\end{aligned}$$

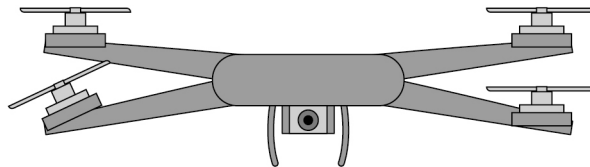
[2 marks]

$$\begin{aligned}\text{angular momentum} &= I\omega; \text{ change for the 4 propellers} = 4 \times 4.8 \times 10^{-5} \times 100 \\ &= 0.0192 \text{ kg m}^2 \text{ s}^{-1}; \text{ drone gains an equal and opposite amount:} \\ \omega &= 0.0192 / 0.021\end{aligned}$$

$$\text{angular speed} = \underline{\quad 0.91 \quad} \text{ rad s}^{-1}$$

0 7 . 8

On another occasion, when the drone is hovering, the drone operator angles one motor-propeller unit to the left as shown in **Figure 16**.

Figure 16

Discuss how the change in angle of the motor-propeller unit will affect the motion of the drone.

[2 marks]

The thrust of this unit now has a horizontal component, so the drone accelerates (moves) to the left.

Its vertical component is smaller, so total upward thrust < weight and the drone accelerates downwards.

18

END OF QUESTIONS

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