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EDEXCEL A LEVEL PHYSICS: QUESTIONS BY TOPIC

Working as a Physicist (1)

A Level Physics Topic 1

106 questions · 735 marks · Mark schemes included

AS & A Level content · Pearson Edexcel 8PH0 / 9PH0 papers, 2016–2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.
Click any row below to jump straight to that sub-topic or question.
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Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

106 questions · 735 marks · 5 sub-topics

SUB-TOPIC 1.1

SI UNITS, BASE UNITS AND HOMOGENEITY

Sub-topic 1.1 · 20 questions · 20 marks · lowest tariff first

5 Which of the following is the unit for tension expressed in SI base units?

- ☒ **A** N
- ☒ **B** N s
- ☒ **C** kg m s^{-1}
- ☒ **D** kg m s^{-2}

(Total for Question 5 = 1 mark)

6 Which of the following are the base units for impulse?

- ☒ **A** $kgms^{-1}$
- ☒ **B** $kgms^{-2}$
- ☒ **C** Nm
- ☒ **D** Ns

(Total for Question 6 = 1 mark)

1 All quantities may be expressed in terms of SI base units.

Select the row of the table that states the SI base units for the given quantity.

		Quantity	SI base unit
☒	**A**	charge	C
☒	**B**	charge	$A\ s^{-1}$
☒	**C**	power	$J\ s^{-1}$
☒	**D**	power	$kg\ m^2\ s^{-3}$

(Total for Question 1 = 1 mark)

2 A student measured the mass, in grams, of a small projectile, and its velocity in kilometres per hour.

To calculate the kinetic energy E_k of the projectile he substituted these quantities into the equation $E_k = ½ mv^2$.

Which of the following should the student multiply the answer by to obtain an answer in joules?

☒ **A** $\frac{1000}{3600^2}$

☒ **B** $\left(\frac{1000}{3600}\right)^2$

☒ **C** $\frac{3600^2}{1000}$

☒ **D** $\left(\frac{3600}{1000}\right)^2$

(Total for Question 2 = 1 mark)

4 The Hooke's law equation is:

$$\Delta F = k\Delta x$$

Which of the following gives the base units of k?

☒ **A** kg s^{-2}

☒ **B** kg m s^{-2}

☒ **C** N m

☒ **D** N m^{-1}

(Total for Question 4 = 1 mark)

4 Which of the following is a base SI unit?

- ☒ **A** ampere
- ☒ **B** coulomb
- ☒ **C** joule
- ☒ **D** newton

(Total for Question 4 = 1 mark)

1 Which row of the table shows a base quantity and its base SI unit?

		Quantity	Unit
☒	**A**	charge	C
☒	**B**	length	m
☒	**C**	mass	g
☒	**D**	temperature	°C

(Total for Question 1 = 1 mark)

6 Which of the following gives the S.I. base units equivalent to the volt?

- ☒ **A** $J\,C^{-1}$
- ☒ **B** $J\,A^{-1}\,s^{-1}$
- ☒ **C** $kg\,m^2\,s^{-2}\,C^{-1}$
- ☒ **D** $kg\,m^2\,s^{-3}A^{-1}$

(Total for Question 6 = 1 mark)

1 Which of the following is a S.I. base quantity?

- ☒ **A** energy
- ☒ **B** length
- ☒ **C** speed
- ☒ **D** velocity

(Total for Question 1 = 1 mark)

1 Select the row of the table that identifies an SI base unit and a derived unit.

		Base unit	Derived unit
☒	**A**	coulomb	ampere
☒	**B**	joule	volt
☒	**C**	newton	kilogram
☒	**D**	second	watt

(Total for Question 1 = 1 mark)

1 Which of the following best describes the newton as used in physical measurements?

- ☒ **A** base quantity
- ☒ **B** base unit
- ☒ **C** derived quantity
- ☒ **D** derived unit

(Total for Question 1 = 1 mark)

4 Which of the following is a valid unit for luminosity?

- ☒ **A** Wm^{-2}
- ☒ **B** Nms^{-2}
- ☒ **C** Js^{-1}
- ☒ **D** Jm^{-2}

(Total for Question 4 = 1 mark)

2 Which of the following is the SI base unit for resistance?

- ☒ **A** Ω
- ☒ **B** VA^{-1}
- ☒ **C** $kgm^2s^{-3}A^{-2}$
- ☒ **D** $kgm^2s^{-1}C^{-2}$

(Total for Question 2 = 1 mark)

3 Which of the following is the SI base unit for the Planck constant?

☒ **A** $\mathrm{N\,m^{-1}\,s^{-1}}$

☒ **B** $\mathrm{N\,m\,s}$

☒ **C** $\mathrm{kg\,m^{2}\,s^{-1}}$

☒ **D** $\mathrm{kg\,m^{-2}\,s}$

(Total for Question 3 = 1 mark)

1 The wavelength of light emitted from a laser can be determined using a diffraction grating. The equation used to calculate the wavelength is

$$n\lambda = d\sin\theta$$

Which row of the table shows possible units for n and d?

		n	d
☒	**A**	no unit	mm^{-1}
☒	**B**	no unit	mm
☒	**C**	mm	no unit
☒	**D**	mm^{-1}	no unit

(Total for Question 1 = 1 mark)

1 Which of the following is the base unit for charge?

- ☒ **A** As
- ☒ **B** C
- ☒ **C** JV^{-1}
- ☒ **D** Q

(Total for Question 1 = 1 mark)

7 Which of the following units is equivalent to the joule?

- ☒ **A** Ns
- ☒ **B** $kg\,m\,s^{-2}$
- ☒ **C** Ws
- ☒ **D** $kg\,m\,s^{-1}$

(Total for Question 7 = 1 mark)

6 Which of the following is the S.I. base unit for breaking stress?

- ☒ **A** Pa
- ☒ **B** $\mathrm{kg\,m^2\,s^{-2}}$
- ☒ **C** $\mathrm{N\,m^{-2}}$
- ☒ **D** $\mathrm{kg\,m^{-1}\,s^{-2}}$

(Total for Question 6 = 1 mark)

1 Which of the following gives the SI base units of stress?

- ☒ **A** $\mathrm{kg\,m\,s^{-2}}$
- ☒ **B** $\mathrm{kg\,m^{-1}\,s^{-2}}$
- ☒ **C** $\mathrm{N\,m^{-2}}$
- ☒ **D** Pa

(Total for Question 1 = 1 mark)

3 Which of the following units is equivalent to the newton?

- ☒ **A** $\mathrm{kg\,m\,s^{-1}}$
- ☒ **B** $\mathrm{kg\,m\,s^{-2}}$
- ☒ **C** $\mathrm{kg\,m^2\,s^{-2}}$
- ☒ **D** $\mathrm{kg\,m^2\,s^{-1}}$

(Total for Question 3 = 1 mark)

SUB-TOPIC 1.2

ESTIMATION AND ORDERS OF MAGNITUDE

Sub-topic 1.2 · 1 question · 1 marks · lowest tariff first

8 A power station provides electrical power at a mean rate of 3500 MW.

Which of the following gives the best estimate of the energy provided to consumers over a period of a year?

1 year = 3.2×10^7 s

- ☒ **A** 1×10^6 J
- ☒ **B** 1×10^{11} J
- ☒ **C** 1×10^{13} J
- ☒ **D** 1×10^{17} J

(Total for Question 8 = 1 mark)

SUB-TOPIC 1.3

ACCURACY, PRECISION, ERRORS AND UNCERTAINTIES

Sub-topic 1.3 · 26 questions · 183 marks · lowest tariff first

5 In an experiment a student is taking a measurement of a time interval in seconds.

He repeats the measurement and collects the following three readings:

3.2 s 3.2 s 3.3 s

Which one of the following is a correct statement?

☒ **A** The reading of 3.3 s is an error.

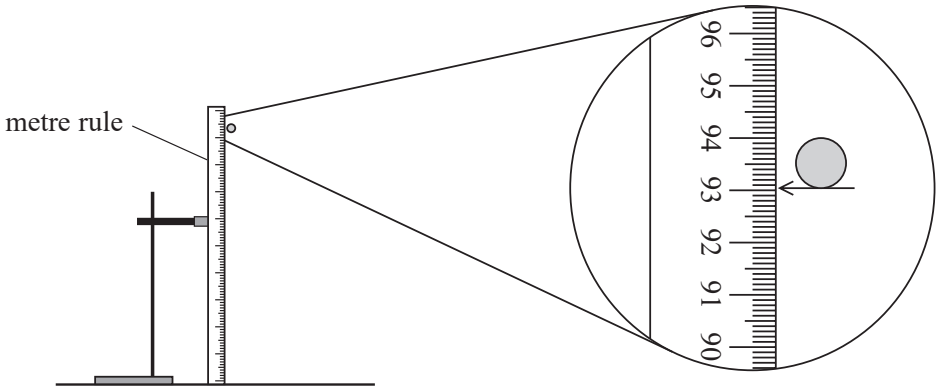
☒ **B** The average should be recorded as 3.23 s.

☒ **C** The uncertainty is 0.1 s.

☒ **D** The error is 0.1 s.

(Total for Question 5 = 1 mark)

5 A student carried out an experiment to determine the acceleration of free fall. The initial height of a ball bearing was measured using a metre rule.



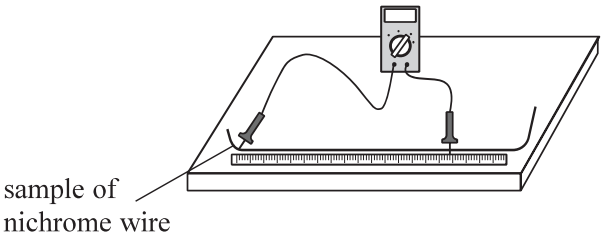
What is the best estimate of the percentage uncertainty in the measurement of height?

- ☒ **A** ±0.001%
- ☒ **B** ±0.01%
- ☒ **C** ±0.1%
- ☒ **D** ±1%

(Total for Question 5 = 1 mark)

Questions 6 and 7 refer to the information below.

An ohmmeter was used to measure the resistance R of a length l of nichrome wire as shown. This was then repeated for different values of l.



7 A metre rule was used to measure l.

The following measurements were recorded.

l_1 / cm	l_2 / cm	l_3 / cm
89.1	89.6	89.4

Which of the following is the most appropriate uncertainty to use for the length of the piece of wire?

- ☒ **A** ±0.1 cm
- ☒ **B** ±0.2 cm
- ☒ **C** ±0.3 cm
- ☒ **D** ±0.4 cm

(Total for Question 7 = 1 mark)

8 In an experiment to determine the wavelength of light, three values for the wavelength are obtained and the mean value calculated.

Wavelength / nm	466	448	473
Mean wavelength / nm	462		

What is the uncertainty, in nm, in these results?

☒ **A** 25

☒ **B** 18

☒ **C** 14

☒ **D** 11

(Total for Question 8 = 1 mark)

Questions 4 and 5 refer to the following information.

The speed v of a transverse wave on a string is given by

$$v = \sqrt{\frac{T}{\mu}}$$

where μ is the mass per unit length of the string and T is the tension in the string.

4 μ can be calculated from measurements of the mass and length of the string.

The percentage uncertainty in the measurement of mass is 0.4%.
The percentage uncertainty in the measurement of length is 0.05%.

Which of the following is the percentage uncertainty in the calculated value for μ?

- ☒ **A** 0.4 + 0.05
- ☒ **B** 0.4 − 0.05
- ☒ **C** 0.4 × 0.05
- ☒ **D** 0.4 ÷ 0.05

(Total for Question 4 = 1 mark)

5 A student measures the diameter of a steel wire in order to determine the cross-sectional area of the wire. The percentage uncertainty in the measurement of the diameter was 1.8%.

Which of the following is the percentage uncertainty in the value for the cross-sectional area?

- ☒ **A** 1.8%
- ☒ **B** (1.8 + 1.8)%
- ☒ **C** (1.8 + 1.8 + 1.8)%
- ☒ **D** (1.8 × 1.8)%

(Total for Question 5 = 1 mark)

4 A ball bearing falling freely through a liquid reaches terminal velocity. The terminal velocity is determined by measuring the time taken for the ball bearing to fall a measured distance.

The measured distance has a percentage uncertainty X.

The measured time has a percentage uncertainty Y.

Which of the following gives the percentage uncertainty in the value for the terminal velocity of the ball bearing?

☒ **A** X + Y

☒ **B** XY

☒ **C** $\frac{X}{Y}$

☒ **D** X – Y

(Total for Question 4 = 1 mark)

1 A physics textbook states that "when carrying out experimental measurements there will always be errors and uncertainties".

(a) Describe what physicists mean by error and by uncertainty.

(2)

(b) Give two reasons why a measurement may have an uncertainty.

(2)

(Total for Question 1 = 4 marks)

1 A practical physics textbook states that "measurements may give a precise value for the quantity being determined but this may not necessarily be an accurate value".

(a) Describe what physicists mean by the terms accuracy and precision.

(2)

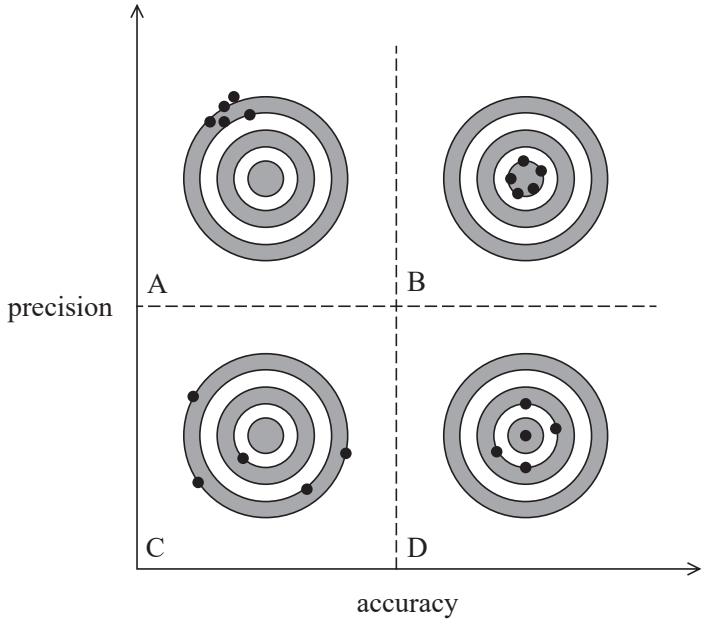
(b) The temperature of the air in a room is measured using a mercury-in-glass thermometer.

Describe how the value for the temperature may be precise but not accurate.

(2)

(Total for Question 1 = 4 marks)

1 A teacher is explaining the differences between accuracy and precision to her students. She draws the following diagram, which shows different degrees of accuracy and precision. The circles represent targets A, B, C and D and the dots represent arrows hitting the targets.



Explain how targets A, B, C and D represent differing degrees of accuracy and precision.

(4)

(Total for Question 1 = 4 marks)

2 A student was given a box of identical glass microscope slides and asked to determine the density of the glass. She used a micrometer to measure the thickness of one of the slides. She repeated this measurement twice in different places and calculated a mean value for the thickness. The thickness of each slide was approximately 1 mm.

(a) Explain how she should have measured the thickness of the slides in order to minimise the percentage uncertainty.

(2)

(b) In her report she wrote

"My value for the mass of the glass slides was precise, because I measured the mass using an electronic balance which was accurate to the nearest 0.01g. I reduced the effect of random error by repeating the measurement several times."

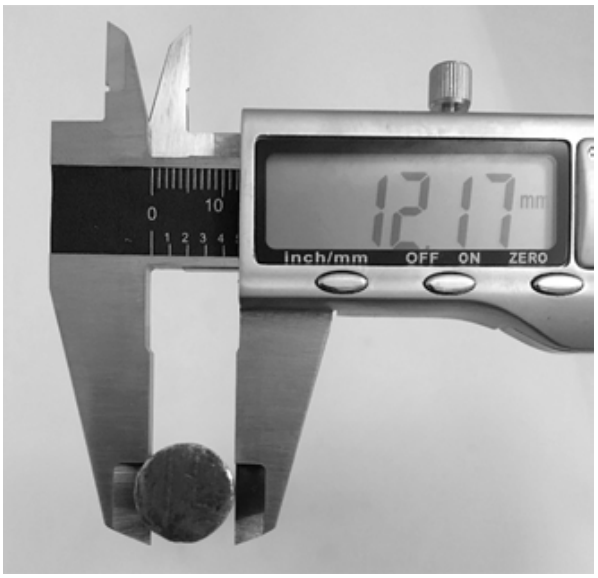
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(4)

(Total for Question 2 = 6 marks)

10 The photographs show two types of caliper being used, in turn, to measure the diameter of an iron rod.

Caliper 1



diameter = 12.17 mm

Caliper 2



diameter = 12.2 mm

(a) State the resolution of each of the calipers and compare their use for measuring the diameter of the rod.

(4)

(b) The value obtained from caliper 2 was used to determine the cross-sectional area of the rod and the electrical properties of the rod were investigated.

Calculate the drift velocity for the charge carriers in the rod when the current in the rod is 1.9 A.

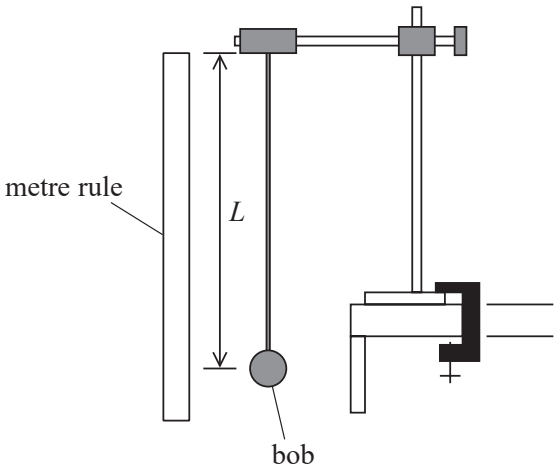
diameter of rod = 12.2 mm
charge carrier density for iron = $1.7 \times 10^{29}\ m^{-3}$

(3)

Drift velocity = ...

(Total for Question 10 = 7 marks)

4 A student set up a "seconds pendulum". This is a simple pendulum for which the time taken to move from the bob's highest position on one side to its highest position on the opposite side is 1.00 s.



(a) Calculate the length L required for the pendulum to be a "seconds pendulum".

(2)

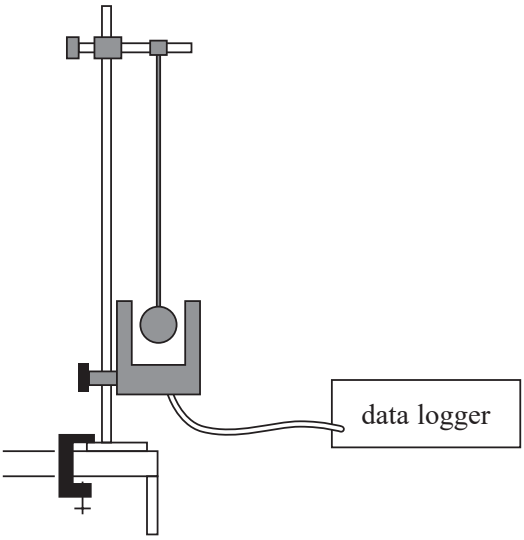
L = ...

(b) The student set the pendulum into oscillation. She used a stopwatch to check the accuracy of the pendulum's period T.

Describe the procedure the student should have used to obtain an accurate value for T.

(2)

(c) Another student suggested that the uncertainty in the measurement of the time period of the pendulum could be reduced by using a light gate and a data logger. The data logger would record the time between successive interruptions of the light beam. Both the data logger and the stopwatch have a resolution of 0.01 s.

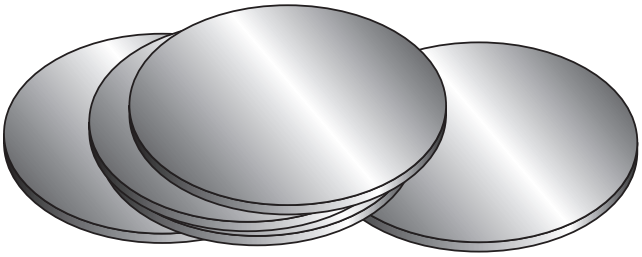


Comment on the student's suggestion of using a data logger rather than a stopwatch.

(4)

(Total for Question 4 = 8 marks)

3 A student is investigating the properties of steel. He has fifty steel discs available.



Each disc has a diameter $d \approx 1.3$ cm and a thickness $t \approx 2$ mm.

(a) State a suitable measuring instrument that could be used with a single disc to measure t.

(1)

.....

.....

(b) A balance which can measure mass with a resolution of 0.2 g is available.

Determine the minimum number of discs that should be placed on the balance together if the percentage uncertainty in the measurement of the mass is to be less than 0.5%.

(4)

density of steel = 7900 kg m^{-3}

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Minimum number of discs = ...

(c) The measured uncertainty in d is ±0.1 mm and the measured uncertainty for t is ±0.05 mm.

Determine the percentage uncertainty in the calculated volume of the disc.

(3)

Percentage uncertainty in volume = ...

(Total for Question 3 = 8 marks)

2 A student released a ping pong ball in front of a metre rule and used a phone camera to record the motion of the ball as it fell. The phone camera captures 60 images per second, which may be played back one image at a time.

(a) The ball was dropped from a height such that it reached its terminal velocity as it passed the metre rule.

(i) Explain how the terminal velocity of the ball could be determined using the phone camera recording.

(4)

(ii) Explain how a systematic error could affect the value obtained for the terminal velocity.

(2)

(b) This experiment could have been attempted using a stopwatch to measure the time as the ping pong ball fell.

Explain an advantage of using a phone camera rather than a stopwatch.

(2)

(Total for Question 2 = 8 marks)

3 Genuine crystal balls are made from clarified quartz rather than glass.
A student was given a small crystal ball and wanted to know whether it was genuine.

(a) The mean diameter of the crystal ball was measured to be 5.06 cm and the mass of the crystal ball was measured to be 175 g.

Show that the density of the material of the crystal ball is about 2600 kg m^{-3}.

(3)

(b) The student measured the diameter of the crystal ball using vernier calipers with a resolution of 0.01 cm.
She measured the mass of the crystal ball using a balance with a resolution of 1 g.

The table gives the densities of clarified quartz and glass.

Material	Density / kg m^{-3}
Clarified quartz	2650
Glass	2590

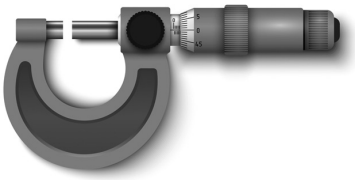
Determine whether the crystal ball was genuine.

(6)

(Total for Question 3 = 9 marks)

12 The resistivity of a metal is an important property of wire used in an electric circuit.

(a) A student carried out an experiment to determine the resistivity of a type of wire. He used a micrometer to measure the diameter d of the wire.



(Source: © Viktor Chursin/Shutterstock)

He recorded the following values.

d_1 / mm	d_2 / mm	d_3 / mm	d_4 / mm
1.40	1.44	1.42	1.41

(i) Calculate the percentage uncertainty in the mean diameter of the wire.

(3)

.....

.....

.....

.....

% uncertainty in mean diameter of wire = ...

(ii) The student used an ohmmeter to measure the resistance R of a 1.65 m length of the wire.

He looked up the resistivity values of some materials.

Material	Titanium	Constantan	Stainless Steel
Resistivity / $10^{-7}\,\Omega\,m$	4.2	4.7	6.9

Identify the material of the wire.

$R = 0.72\,\Omega$

(3)

(b) Nichrome wire is often used in heating elements. Nichrome wire is used to make a coil for a 65 W mains powered heater. The nichrome wire has a resistance per metre of $87.5\,\Omega\,m^{-1}$.

Calculate the length of wire required.

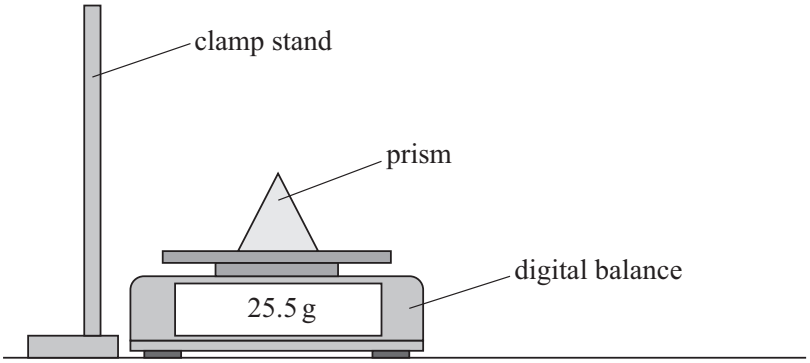
potential difference across the coil = 230 V

(3)

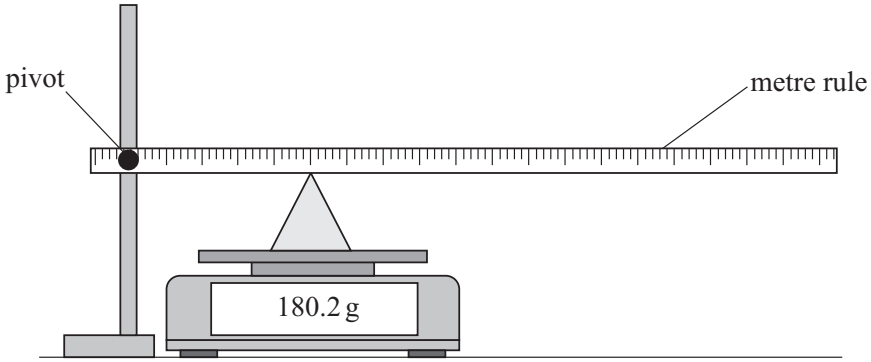
Length of wire required = ...

(Total for Question 12 = 9 marks)

3 A student uses a digital balance. She sets the balance to zero and then places a prism on the balance, as shown.



A uniform metre rule is pivoted at its 5.0 cm mark. The metre rule is then supported horizontally at the 30.0 cm mark by the prism, as shown below.



(a) (i) The metre rule is in equilibrium.

Explain why the increase in mass recorded by the balance is not equal to the mass of the metre rule.

(2)

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.....

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.....

.....

(ii) Calculate the weight of the metre rule. You should take moments about the pivot.

(4)

Weight of metre rule = ...

(b) The student wants to reduce the percentage uncertainty in the value obtained for the weight of the metre rule.

The student repeated her determination of the weight of the metre rule. She moved the prism towards the centre of gravity of the metre rule before taking moments about the pivot.

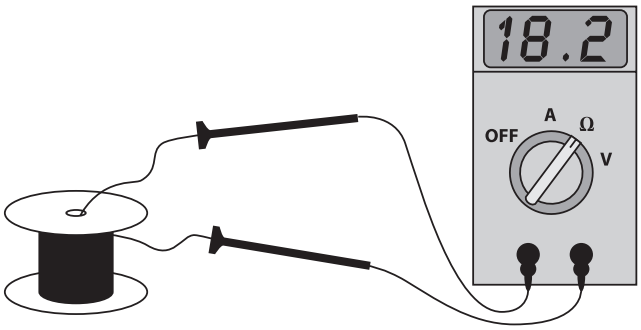
Deduce whether the percentage uncertainty in the value obtained for the weight of the metre rule is reduced by the student moving the prism. No calculations are required.

(3)

(Total for Question 3 = 9 marks)

6 A student carried out an experiment to determine the resistivity of nichrome wire.

He used an ohmmeter to measure the resistance of a length of nichrome wire as shown.



The diameter of the wire was measured as 0.27 mm ± 0.01 mm.
The length of the wire was measured as 1.25 m ± 0.05 m.

(a) Determine which of the three measurements introduces the greatest uncertainty into the value for the resistivity.
Your answer should include calculations.

(4)

(b) Explain how the student could reduce the uncertainty in the measurement of the diameter.

(2)

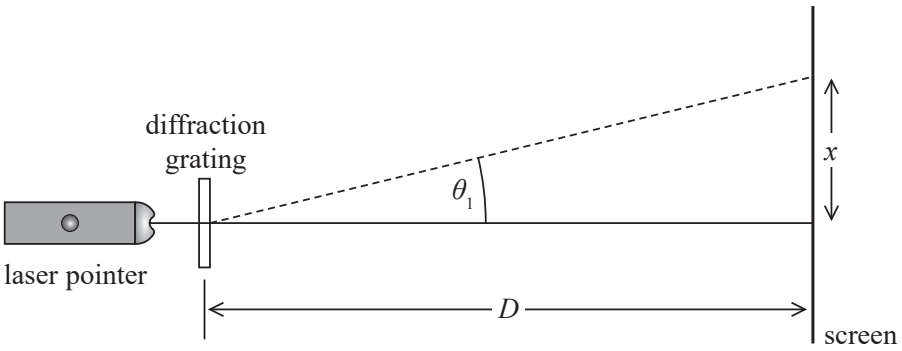
(c) Calculate the minimum value of resistivity possible from the student's data.

(4)

Minimum resistivity = ...

(Total for Question 6 = 10 marks)

11 Light from a laser pointer was passed through a diffraction grating. The light was perpendicular to the diffraction grating as shown. A diffraction pattern was produced on a screen.



The distance between the first order maximum and the central maximum of the diffraction pattern was x. The distance between the diffraction grating and the screen was D.

(a) Distance x was measured to be 0.500 m with a metre rule. The wavelength of light λ_1 from the laser pointer was 650 nm.

The laser pointer was replaced with one that produced light of a different wavelength. The new distance x was measured to be 0.400 m.

$D = 1.45$ m

Calculate the wavelength λ_2 of the light emitted by the replacement laser pointer.

(5)

$\lambda_2 =$ .....

(b) Explain one modification to this method that would decrease the uncertainty in the calculated value of λ_2.

(2)

(c) In another experiment, the light from the laser pointer was not quite perpendicular to the screen.

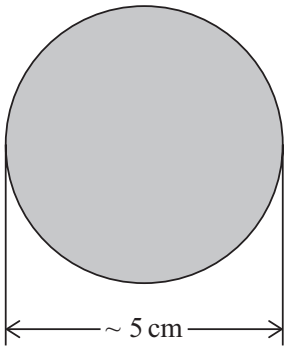
Explain how this would change the diffraction pattern produced on the screen.

(3)

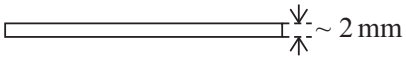
(Total for Question 11 = 10 marks)

7 A student has 10 identical flat metal discs. One of the discs is shown. Each disc has a diameter d of about 5 cm and a thickness t of about 2 mm.

View of disc from above



Side view of disc



The student determined the density of the metal the discs are made from.

She used a half-metre rule to measure d for one of the discs. She used vernier calipers to measure t for one of the discs.

The student then repeated this process for two more discs and calculated average values for d and t of the discs.

(a) Describe improvements to the student's method that would give more accurate values for d and t of the discs.

(4)

(b) The student determined the average mass of a disc to be 42.5 g ± 0.5 g.

Calculate the density of the material the discs are made from and the percentage uncertainty in this value.

average diameter of disc = 5.2 cm ± 0.1 cm
average thickness of disc = 1.9 mm ± 0.1 mm

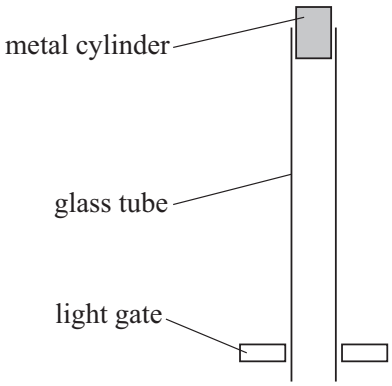
(6)

Density = ...

Percentage uncertainty = ...

(Total for Question 7 = 10 marks)

12 In an experiment to determine the acceleration of free-fall, g, a metal cylinder was dropped from rest down a glass tube. A light gate was positioned close to the outside of the glass tube, as shown.



The light gate was connected to a data logger that recorded the time t taken for the cylinder to pass the gate.

(a) A student recorded the following data.

t_1 / ms	t_2 / ms	t_3 / ms	t_4 / ms
7.85	7.81	7.79	7.80

(i) The student omitted t_1 when calculating the mean time. He justified this by stating that t_1 is an anomalous result.

Another student stated that the correct mean time should use all the data in the table.

Explain who is correct.

(2)

.....

.....

.....

.....

(ii) Calculate the percentage uncertainty in the mean time t_{mean}.

(3)

Percentage uncertainty in t_{mean} = ...

(iii) The student used the mean time to calculate the velocity of the metal cylinder as it moved past the light gate.

State the extra measurement the student must have made to calculate this velocity.

(1)

(b) The metal cylinder fell through a distance 0.75 m before reaching the light gate.

(i) Calculate the velocity of the metal cylinder as it reached the light gate.

(2)

Velocity = ...

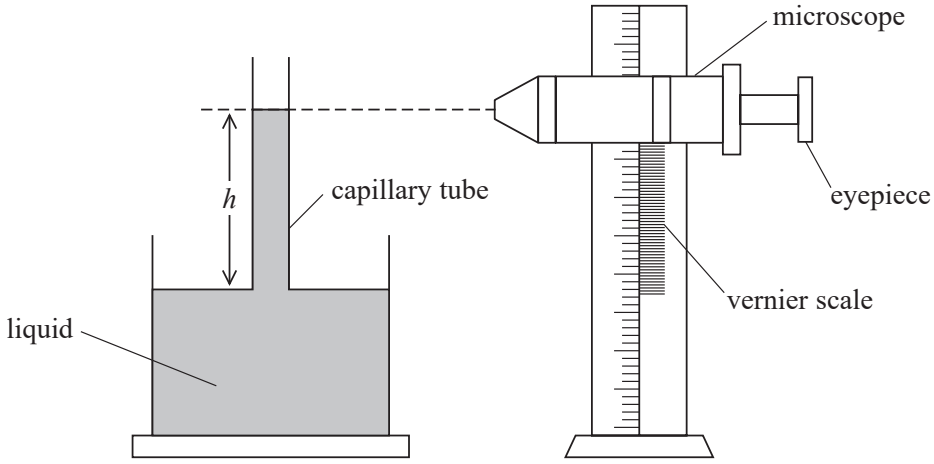
(ii) Explain why a light gate and data logger were used in this experiment rather than a stopwatch. You should refer to your answer to (b)(i).

(3)

(Total for Question 12 = 11 marks)

5 A student measured the height h of a liquid column in a capillary tube. She used a travelling microscope to make measurements of the positions of the top and bottom of the liquid column.

The travelling microscope consists of a simple microscope that can be moved vertically along a vernier scale.



(a) The student used a capillary tube with an internal radius r equal to 0.10 mm and recorded the following readings from the vernier scale.

Bottom of liquid column / cm	Top of liquid column / cm
12.00	27.10

(i) State the uncertainty in each of these readings.

(1)

.....

(ii) Calculate the percentage uncertainty in the student's value of h.

(2)

.....

.....

.....

.....

Percentage uncertainty in h = ...

(iii) The student repeated the measurement of h for capillary tubes of different radii.

The table shows the student's final data.

r / mm	$1/r$	h / cm
0.09	11.1	16.56
0.10	10.0	15.1
0.12	8.3	12.6
0.15	6.7	10.33

Criticise the student's recording of the data.

(2)

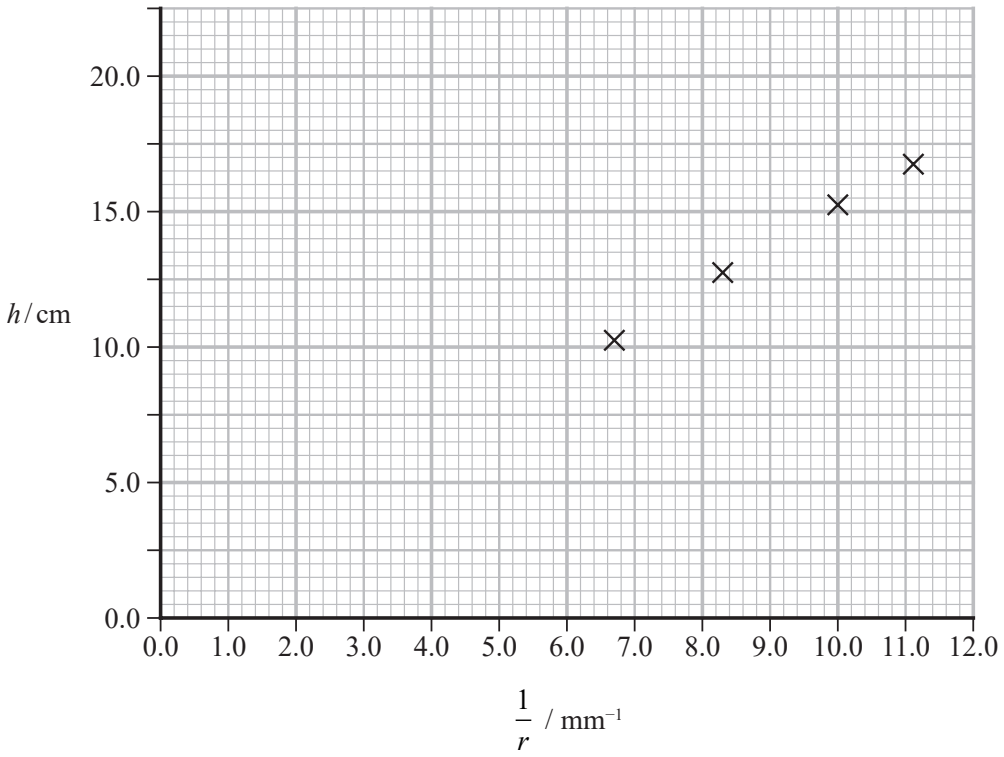
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(b) The student plotted the following graph.



(i) Determine the height of the liquid column that the student could expect for a tube with an internal radius of 0.11 mm.

(3)

Height of liquid column = ...

(ii) In her notes it stated that

$$h = \frac{k}{r} \qquad \text{where } k \text{ is constant}$$

Assess the extent to which the student's data supports this relationship.

(4)

(Total for Question 5 = 12 marks)

2 A student made measurements to determine if some gold coins were made from pure gold. The coins that were available to the student are shown below.



(Source: © Bjoern Wylezich/Shutterstock)

(a) The student used digital calipers to measure the thickness t and the diameter d of one of the coins.

(i) Calculate the volume V of the coin, and the percentage uncertainty in V.

$t = 1.54\,\text{mm}$
$d = 22.16\,\text{mm}$

(7)

$V =$ .....

Percentage uncertainty in $V =$ .....

(ii) The student measured the mass of the coin using an electronic balance.
The balance had a resolution of 0.1 g.

Assess whether the coin could be made from pure gold.

density of pure gold = 1.93×10^4 kg m^{-3}
mass of coin = 11.2 g

(4)

(b) The student's experimental method could have been improved.

Explain two changes the student could have made to the experimental method.

(4)

(Total for Question 2 = 15 marks)

10 A spring is made from loops of thick steel wire as shown.



There are two extra loops, one on each end of the spring.

(a) A student determined the length of steel used to make the spring by using vernier calipers to measure the width w of the spring.
The length of wire l on each loop is given by $l = \pi w$

The student obtained the following values for w.

***w* / mm**	15.3	15.2	15.4	15.3

(i) Calculate l.

(3)

$l =$ .....

(ii) Estimate the percentage uncertainty in your value for l.

(2)

% uncertainty in $l =$ .....

(iii) Calculate the total length L of wire used to make the spring.

(2)

.....

.....

.....

L = ...

(b) The student measured the diameter d of the steel wire and obtained a value of 2.52 mm.

(i) Explain which instrument he used to measure the diameter.

(2)

.....

.....

.....

(ii) Estimate the percentage uncertainty in the student's value for d.

(1)

.....

.....

% uncertainty in d = ...

(iii) The student used a balance to measure the mass m of the spring.
He obtained a value of 32.0 ± 0.5 g.

Estimate the percentage uncertainty in the mass of the spring.

(1)

.....

.....

% uncertainty in m = ...

(iv) The student calculated the density ρ of the steel using the equation

$$\rho = \frac{m}{V}$$

Calculate the percentage uncertainty in his value for the density of steel.

(1)

.....

.....

% uncertainty in value for density of steel = ...

(v) Determine whether the data collected leads to a value for the density of steel in agreement with the standard value.

density of steel = 7 800 kg m^{-3}

(4)

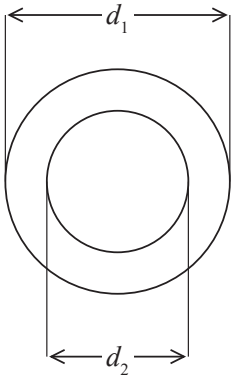
(Total for Question 10 = 16 marks)

11 The photograph shows some metal washers. A student carried out an experiment to determine the density of the metal the washers are made from.



(Source: © NJH Photography/Shutterstock)

Each washer has a diameter d_1 of about 4.5 cm. The internal diameter d_2 of each washer is about 2.5 cm. Each washer has a thickness t of about 4 mm.



(a) The student used a half metre rule to make measurements of a washer.

Comment on the student's choice of measuring instrument.

(3)

(b) The student measured t for each of the five washers and then calculated a mean value.

Explain how the student could modify her method to obtain a more accurate mean value for t.

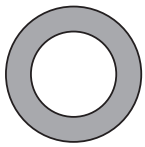
(3)

(c) The student obtained the following mean values.

$d_1 = 4.52\,\text{cm} \pm 0.02\,\text{cm}$

$d_2 = 2.53\,\text{cm} \pm 0.02\,\text{cm}$

She calculated the area A of a washer indicated by the shaded section below.



She used the formula $A = \frac{\pi}{4}(d_1 + d_2)(d_1 - d_2)$

(i) Show that the percentage uncertainty in her value for the area of a washer is about 3%.

(4)

(ii) The student obtained the following values of t for each of the five washers.

t / mm	4.3	4.2	4.1	3.9	4.0

The table shows the density of iron and steel.

Metal	Iron	Steel
Density / g cm^{-3}	6.9	7.9

Deduce whether the washers are made from iron or steel.

mean mass of a washer = 32.0 g

The uncertainty in the mass is negligible.

(6)

(Total for Question 11 = 16 marks)

SUB-TOPIC 1.4

PRACTICAL TECHNIQUES AND EXPERIMENTAL DESIGN

Sub-topic 1.4 · 43 questions · 369 marks · lowest tariff first

1 A student wanted to measure the thickness of a single sheet of aluminium foil.
Which of the following instruments would be the most appropriate to make this measurement?

- ☒ **A** measuring tape
- ☒ **B** micrometer screw gauge
- ☒ **C** ruler
- ☒ **D** vernier calipers

(Total for Question 1 = 1 mark)

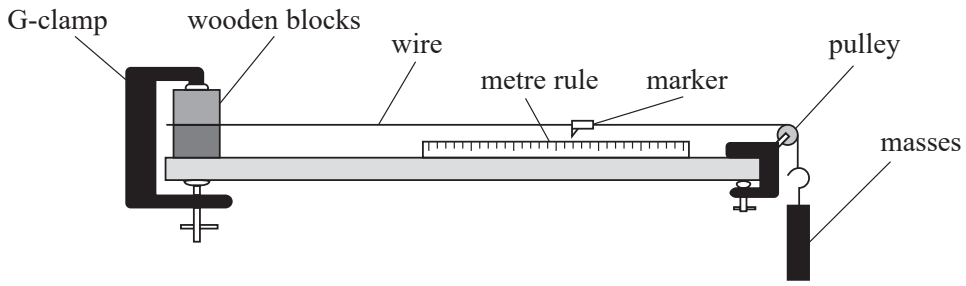
2 A student carries out an investigation to determine the Young modulus of a material.

Which of the following gives two measuring instruments the student should use?

- ☒ **A** calipers and stopwatch
- ☒ **B** metre rule and micrometer
- ☒ **C** metre rule and stopwatch
- ☒ **D** micrometer and calipers

(Total for Question 2 = 1 mark)

10 A student carries out an investigation to measure the Young modulus of the material of a wire. He clamps one end of the wire and passes the other end over a pulley as shown.



The student measures the length and diameter of the wire. He hangs masses from the free end of the wire and completes a table with values of mass and extension.

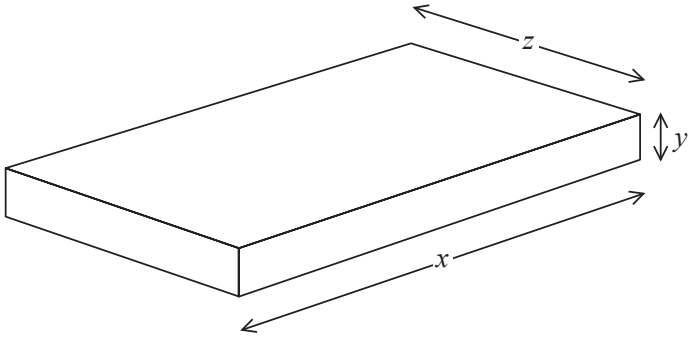
Describe how the data collected should be used to determine the Young modulus using a graphical method. Your answer should include a sketch of the expected graph.

(4)

(Total for Question 10 = 4 marks)

2 A student carries out measurements to determine the density of glass. The student has 20 glass microscope slides available.

The approximate dimensions of one slide are shown.



$x \approx 75\,\text{mm}$
$y \approx 1\,\text{mm}$
$z \approx 25\,\text{mm}$

(a) The density is calculated using the equation

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Describe how the student can determine an accurate value for the density of the glass. Your answer should include the measuring instruments required.

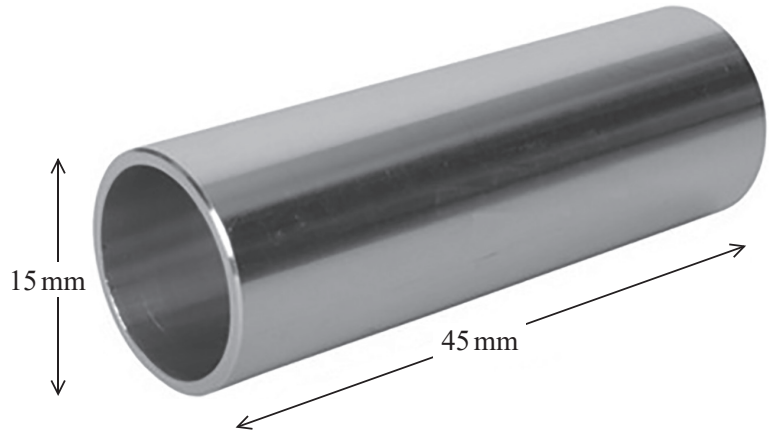
(4)

(b) State one precaution that the student should take to ensure the measurements are accurate.

(1)

(Total for Question 2 = 5 marks)

1 An engineer was checking the dimensions of a steel tube. The tube had a length of about 45 mm and an external diameter of about 15 mm as shown.



She used a digital micrometer to measure the diameter of the tube. Before taking the reading she closed the jaws of the micrometer to check for a zero error.

(a) State the type of error she avoided by doing this.

(1)

(b) Describe the procedure she should follow to determine an accurate value for the external diameter of the tube.

(3)

(c) The engineer determined the length of the tube using the micrometer. The reading on the micrometer scale was 45.043 mm. She recorded the reading as 45.0 mm. State why recording a reading of 45.043 mm could not be justified.

(1)

(Total for Question 1 = 5 marks)

4 A student carried out an experiment to determine the focal length of a converging lens.

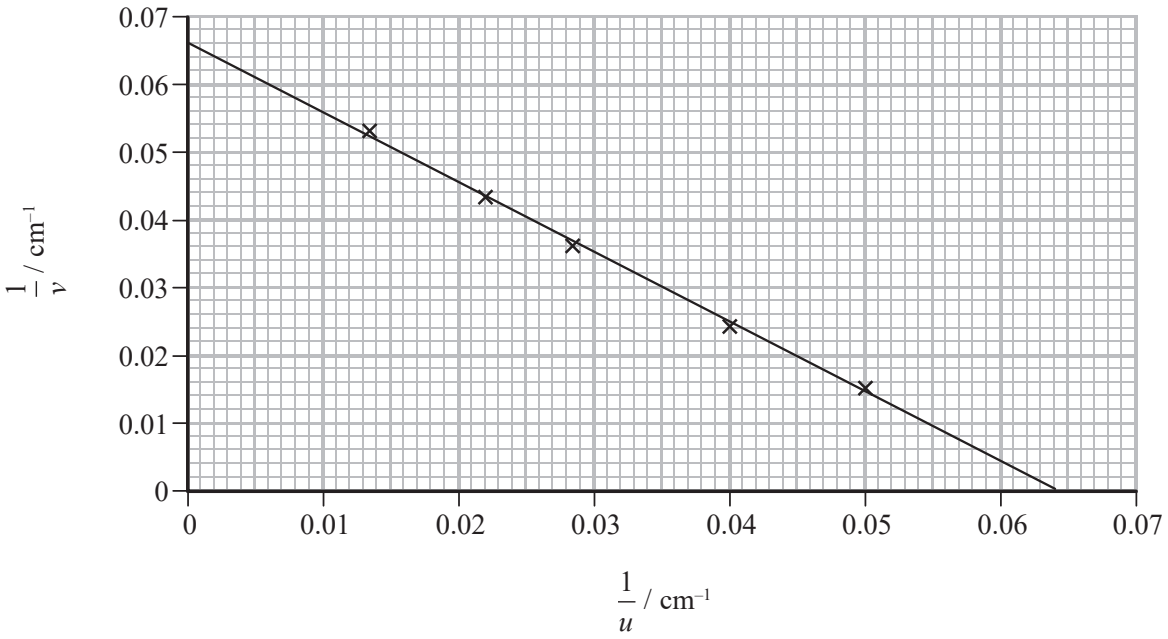
He placed the lens a distance u from an illuminated object. He placed a screen on the other side of the lens and moved the screen until a sharp image of the object was produced. He measured the corresponding image distance v.

The student repeated the procedure for four more values of u.

In his lab report he wrote:

"I made an initial determination of the focal length of the lens and concluded that it was about 15 cm. When I plotted a graph it confirmed my initial determination of the lens focal length."

The student's graph is shown.



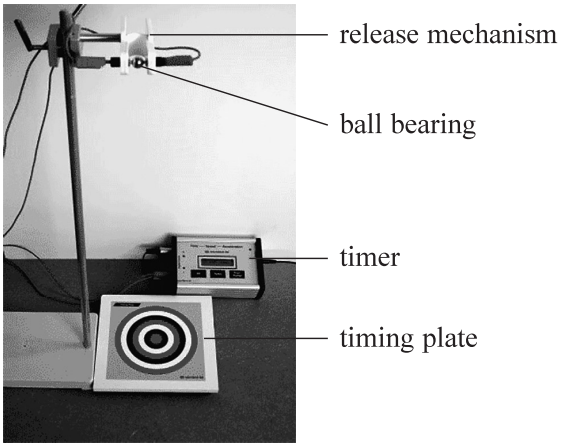
Comment on whether the student's data is consistent with his initial determination of the focal length of the lens.

(5)

(Total for Question 4 = 5 marks)

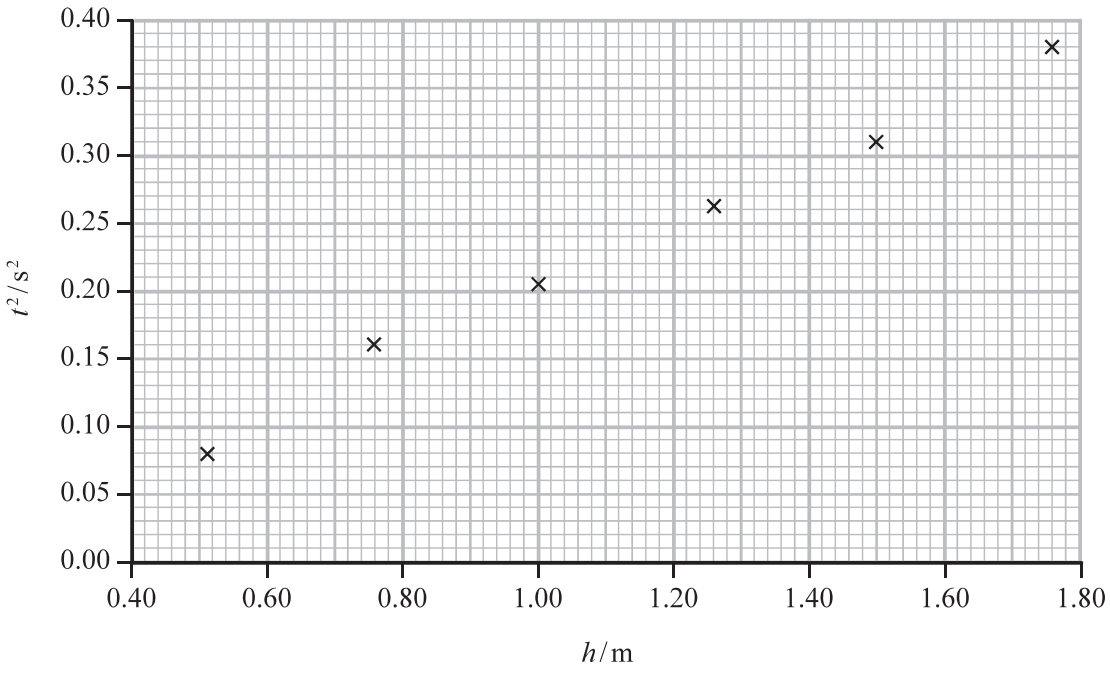
10 A student carried out an experiment to determine the acceleration of free-fall g using the apparatus shown in the photograph.

A ball bearing was released from a measured height h and a timer automatically started. On hitting a timing plate, the ball bearing stopped the timer and the time t was displayed on the timer. This was repeated for different values of h.



The uncertainty in t was ± 3%. The uncertainty in h was ± 1%.

The student plotted a graph of t^2 against h and used it to determine a value for g.



The student concluded that her value for g was consistent with the accepted value.

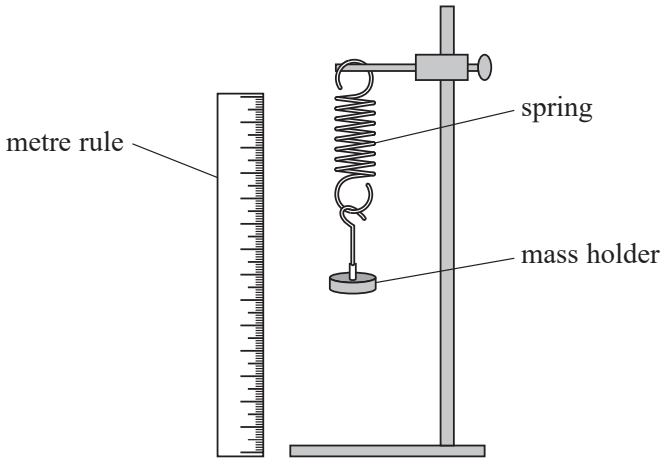
Comment on the student's conclusion. Your answer should include a calculation of g from the student's data.

You may assume that the percentage uncertainty in your value of g is the same as if the value were calculated from just one pair of readings.

(5)

(Total for Question 10 = 5 marks)

1 A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached, as shown. The position of the bottom of the mass holder was determined using a metre rule.



(a) The position of the bottom of the mass holder was recorded. The spring was stretched by adding masses to the mass holder and the new positions were determined. The extension of the spring for each mass was calculated.

The results are shown in the table.

Mass / kg	Extension / m
0.05	0.019
0.10	0.042
0.15	0.058
0.20	0.085
0.25	0.1
0.35	0.14

Criticise the recording of these results.

(2)

.....

.....

.....

.....

(b) Describe how the student should determine the extension of the spring as accurately as possible.

(3)

.....

.....

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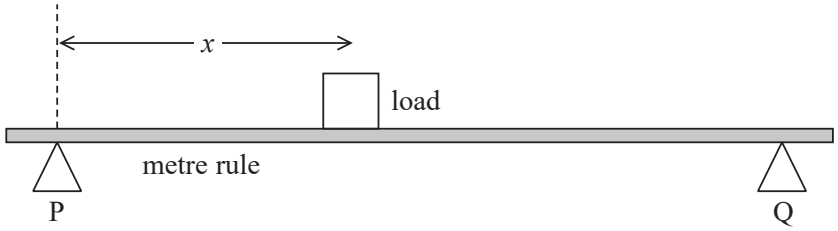
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(Total for Question 1 = 5 marks)

16 A student investigated how the supporting forces on a bridge vary as traffic moves across the bridge.

The student made a simple model of a bridge using a metre rule. The metre rule rested on two supports, P and Q, as shown.



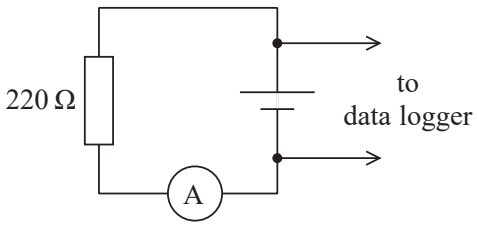
The upward force on the metre rule at P was F_P. The upward force on the metre rule at Q was F_Q.

A load was placed on the metre rule a distance x from support P. Forces F_P and F_Q were measured for different values of x.

Explain how F_P and F_Q changed as x was increased.

(Total for Question 16 = 5 marks)

2 A student is investigating how the internal resistance of a dry cell varies over time.
She sets up the circuit shown to draw current from the cell.



The student proposes to use a data logger to monitor the terminal potential difference (p.d.) of the cell over a period of time.

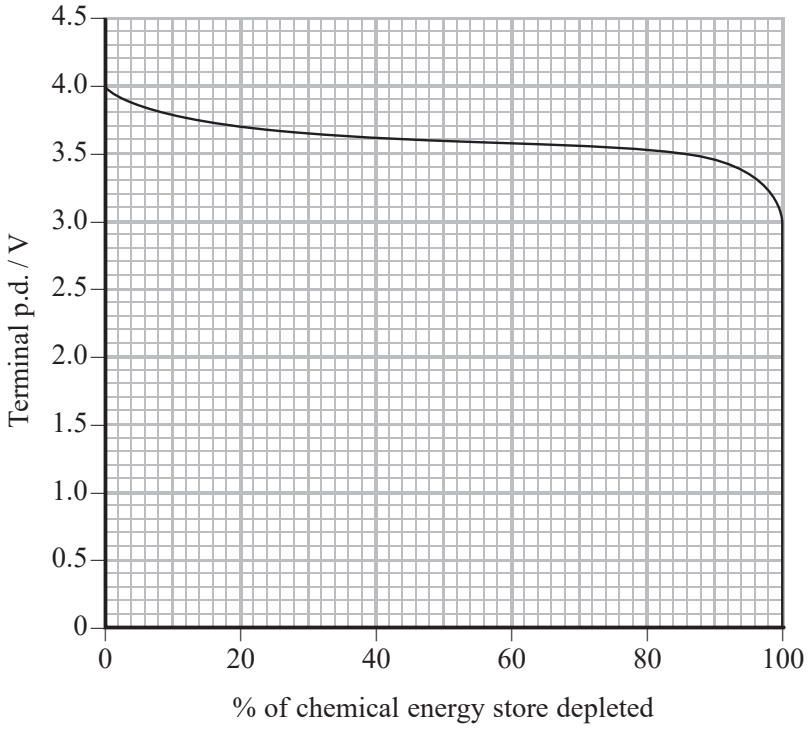
(a) State why a data logger would be suitable to collect data in this investigation.

(1)

.....

.....

(b) The graph shows how the terminal p.d. varies as the chemical energy store in the cell is depleted.



(i) Explain, using the graph, why the current drawn from the cell decreases as the chemical energy store in the cell is depleted.

(2)

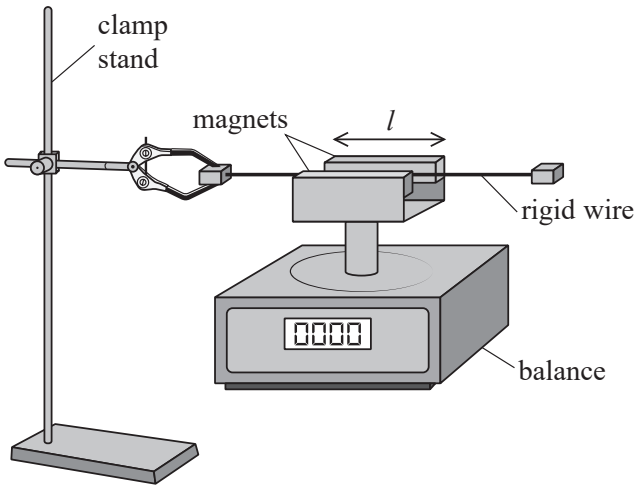
(ii) Determine the internal resistance of the cell when its chemical energy store is 80% depleted. Assume that the e.m.f. of the cell remains constant at 4.0 V.

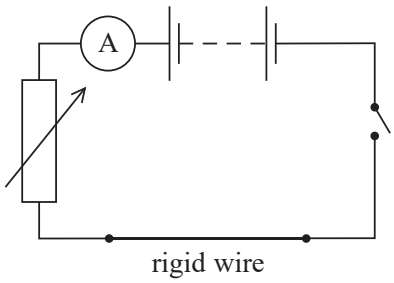
(3)

Internal resistance = ...

(Total for Question 2 = 6 marks)

1 A student set up the apparatus shown. A length of rigid wire was held horizontally by a clamp in a uniform magnetic field of flux density B.
The circuit connected to the rigid wire is also shown.





With the switch open, the balance was set to zero. When the switch was closed a current I in the circuit was recorded by the ammeter and the reading on the balance increased.

(a) The length l of wire in the magnetic field was 15.5 cm. When the current in the circuit was 4.55 A, the reading on the balance increased by 5.65 g.

Calculate the magnetic flux density B in the region of the rigid wire.

(3)

.....

.....

.....

.....

B = ...

(b) The student wrote the following statement

"The balance could read to the nearest 0.01 g, which makes my values for the magnetic force both accurate and precise."

Comment on this statement.

(3)

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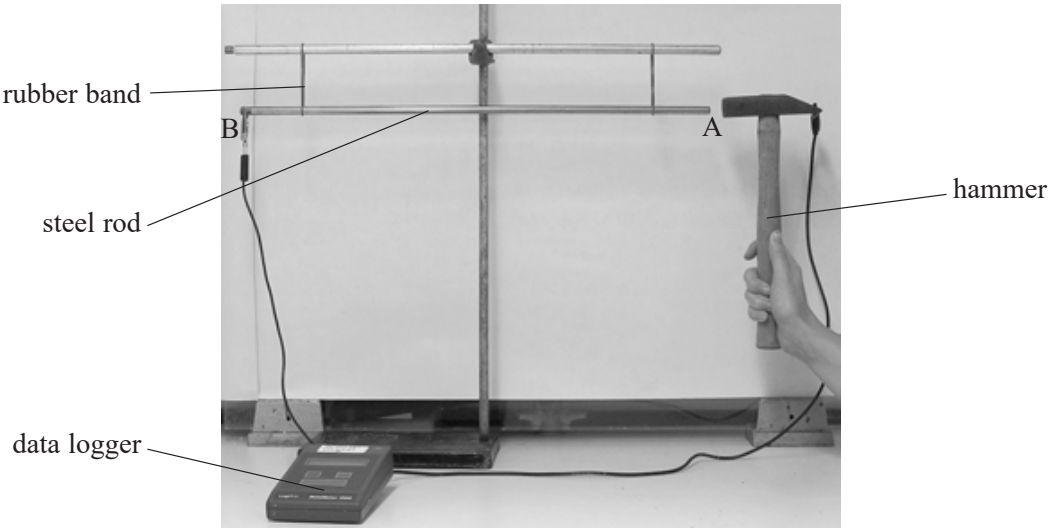
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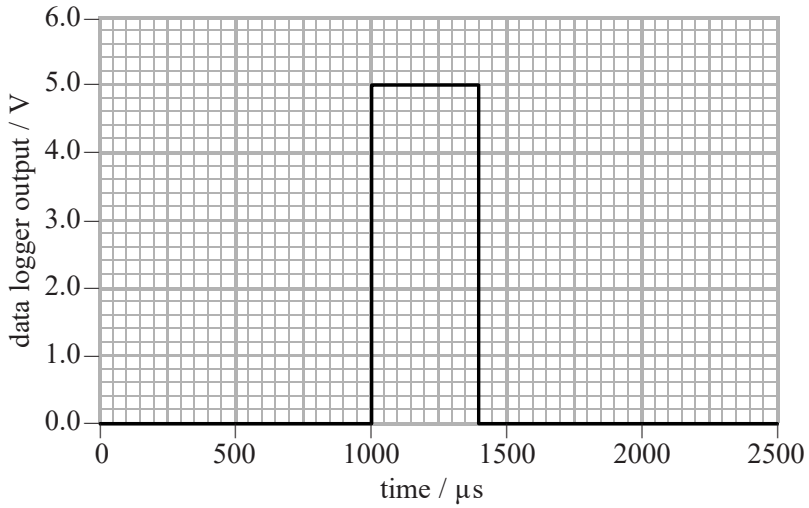
(Total for Question 1 = 6 marks)

7 A teacher is demonstrating how to measure the speed of sound in a steel rod. The equipment comprises a hanging steel rod and a hammer connected to a data logger as shown.



The rod is tapped at A with the hammer. A compression pulse travels to B and is reflected back. When the reflection reaches A the hammer loses contact with the rod. Whilst the hammer is in contact with the rod the output from a 5 V supply is recorded by the data logger.

The graph shows the output from the data logger for one hammer tap.



(a) Explain why a data logger is appropriate for this demonstration.

(2)

(b) (i) Use the graph to show that the speed of the pulse in the rod is about 6000 m s^{-1}.

length of steel rod = 1.18 m

(3)

(ii) The speed of sound v in the rod depends on the Young modulus E and the density ρ of the material of the rod as given by the equation

$$v = \sqrt{\frac{E}{\rho}}$$

Calculate the Young modulus of steel.

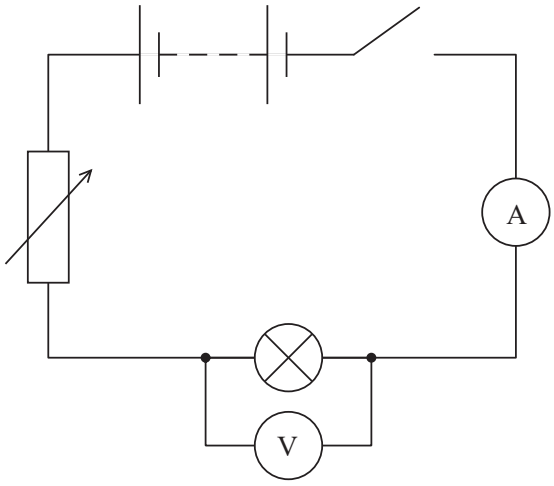
ρ_{steel} = 7850 kg m^{-3}

(2)

Young modulus of steel = ...

(Total for Question 7 = 7 marks)

4 A student set up the circuit shown and measured the current I through the filament lamp for a range of values of potential difference (p.d.) V.



The student's data is shown in the table.

V / V	I / A
3.0	0.6
4.0	0.75
6.0	1.00
8.0	1.20
10.0	1.35
12.0	1.5

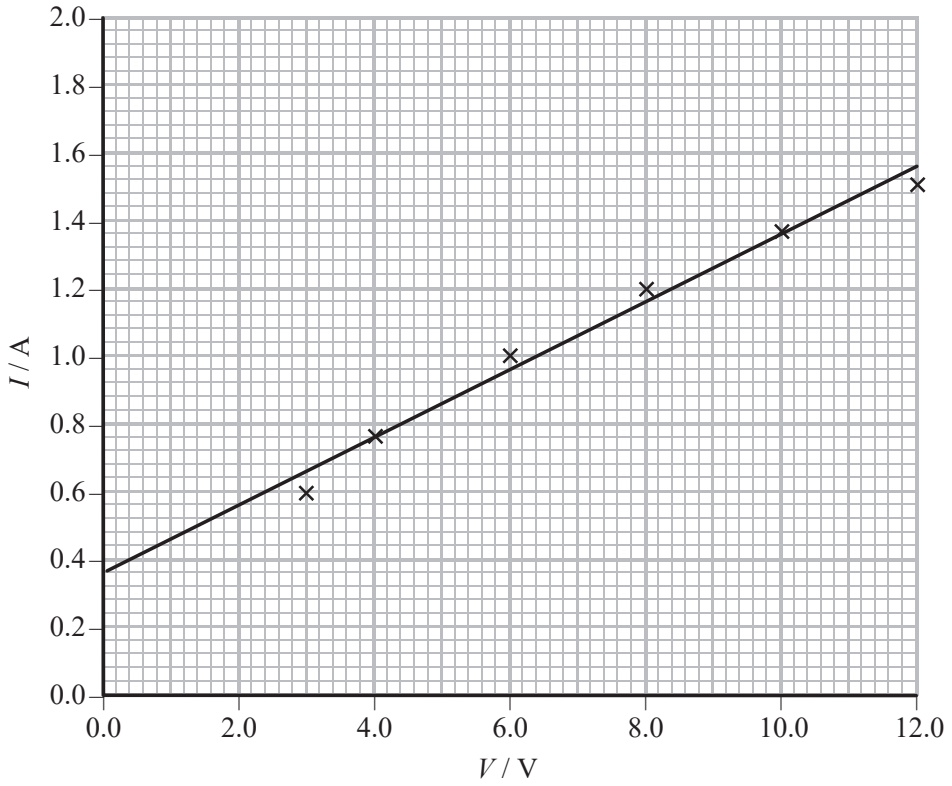
(a) Criticise the student's recording of the data.

(1)

.....

.....

(b) The student drew a graph of how current varies with p.d. She drew a straight line on the graph and claimed that the data demonstrates that the filament lamp obeys Ohm's law because the graph is linear.



Assess the validity of the student's statement.

(4)

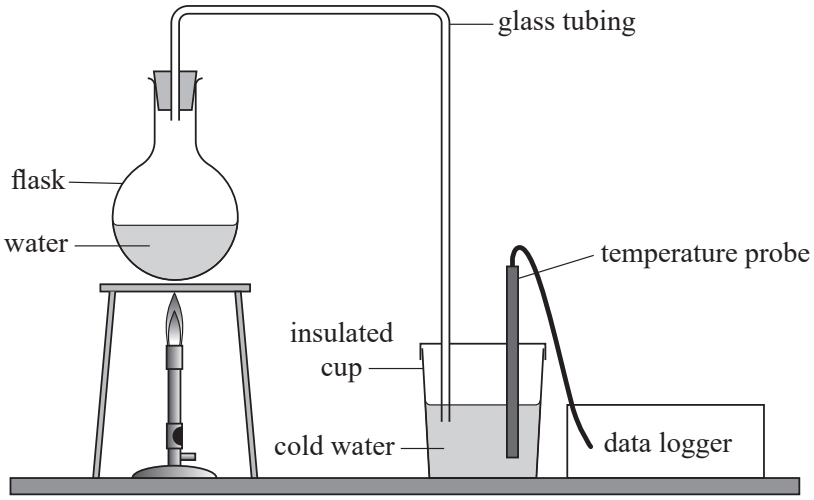
(c) Using the circuit shown the student was unable to obtain data for p.d.s less than 2.5 V.

Draw a diagram of a circuit the student could have used to enable a full range of p.d.s from 0 to 12 V to be investigated.

(2)

(Total for Question 4 = 7 marks)

7 A student carried out an experiment to determine the specific latent heat of vaporisation of water using the apparatus shown.



The water in the flask was heated and steam was forced out of the flask and through the glass tubing into the cold water in the insulated cup. The steam condensed as it passed into the cold water.

(a) The initial temperature of the cold water was 18.5 °C and the mass of water in the cup was 255.0 g. After steam had been passed through the water for some time the temperature had risen to 26.0 °C and the mass of the water in the cup was 258.3 g.

Calculate the specific latent heat of vaporisation of water.

(3)

specific heat capacity of water = 4190 J kg^{-1} K^{-1}

.....

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Specific latent heat of vaporisation of water = ...

(b) (i) Explain why the water was heated to boiling point and left boiling for a few minutes before the insulated cup of cold water was put in place.

(2)

(ii) Identify a significant source of error in this experiment and the steps that should be taken to minimise its effect on the calculated value of the specific latent heat of vaporisation of water.

(2)

(Total for Question 7 = 7 marks)

2 A student determined the specific heat capacity of aluminium.

She used an electrical heater to heat an aluminium block and measured the temperature of the block with a digital thermometer.

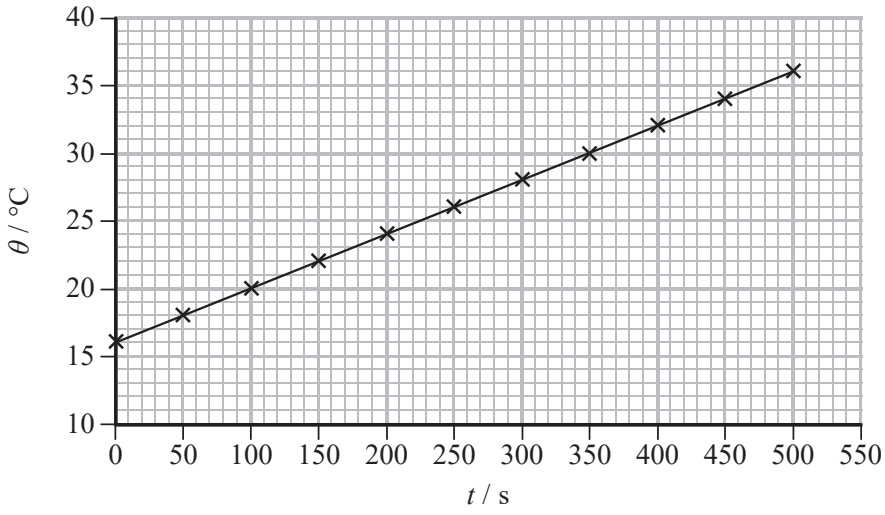
(a) She connected the electrical heater into a circuit and took measurements to determine the power of the heater.

Draw a circuit diagram of a suitable circuit.

(2)

(b) The student monitored the temperature θ of the aluminium block over the time t for which the heater was switched on.

Her results are plotted on the graph.



(i) Determine the specific heat capacity of aluminium.

power of heater = 37.5 W
mass of aluminium block = 0.986 kg

(3)

Specific heat capacity of aluminium = ...

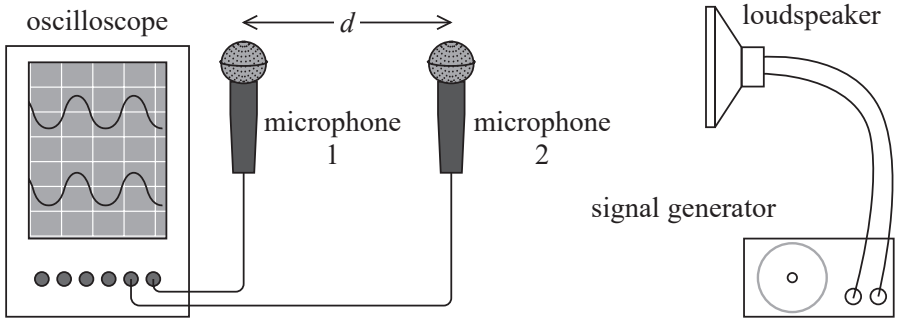
(ii) The student looked up the accepted value for the specific heat capacity of aluminium. Using this value, the student predicted that it should have taken 240 s for the temperature of the aluminium block to increase by 10 °C.

Explain the difference between the predicted time and the student's actual observations.

(2)

(Total for Question 2 = 7 marks)

6 In an experiment to determine the speed of sound in air a student connected two microphones to an oscilloscope, as shown.



The microphones detect sound from the loudspeaker, converting it to an electrical signal. The signal is displayed on the oscilloscope screen.

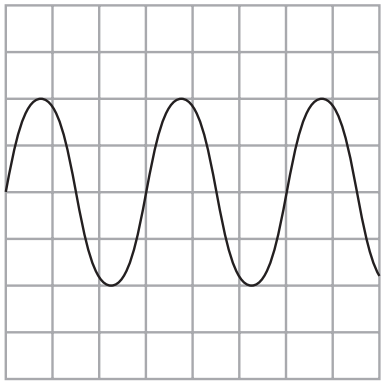
Both microphones were initially positioned the same distance from the loudspeaker. The two signals were in phase on the oscilloscope screen. The student slowly moved microphone 2 towards the loudspeaker, until the two signals on the oscilloscope were in phase again. He then measured the distance d between the microphones to determine the wavelength λ of the sound waves.

$d = 20.5\,\text{cm}$

(a) Comment on the student's experimental technique to determine λ.

(2)

(b) The oscilloscope trace for the signal from microphone 1 is shown below.



The time base of the oscilloscope was set to $0.20\,\text{ms}\,\text{div}^{-1}$.

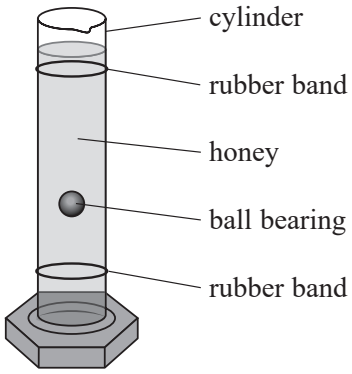
Determine a value for the speed of sound in air.

(5)

Speed of sound = ...

(Total for Question 6 = 7 marks)

10 A student carried out an experiment to determine the viscosity of some honey. He filled a tall glass cylinder with honey as shown, and timed a ball bearing as it fell through the honey.



(a) The student placed rubber bands near the top and bottom of the cylinder. He started a stopwatch when the ball bearing passed the first band and stopped the stopwatch when the ball bearing passed the second band. He repeated this several times to determine a mean time.

Criticise the student's method.

(2)

.....

.....

.....

.....

(b) The time t for the sphere to fall through a distance of 25.0 cm is shown in the table.

t/s			
6.40	6.35	6.36	6.38

(i) Show that the mean velocity v of the ball bearing is about 0.04 m s^{-1}.

(3)

.....

.....

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.....

(ii) The student had three different types of honey available.

Viscosity η is given by the following expression

$$\eta = \frac{2r^2g\left(\rho_B - \rho_H\right)}{9v}$$

radius r of ball bearing = 5.50×10^{-3} m
density of ball bearing $\rho_B = 7750\,\text{kg m}^{-3}$
density of honey $\rho_H = 1360\,\text{kg m}^{-3}$

Viscosity (at 20 °C) / Pa s		
Honey A	Honey B	Honey C
10.6	12.5	13.6

Deduce which honey the student used.

(2)

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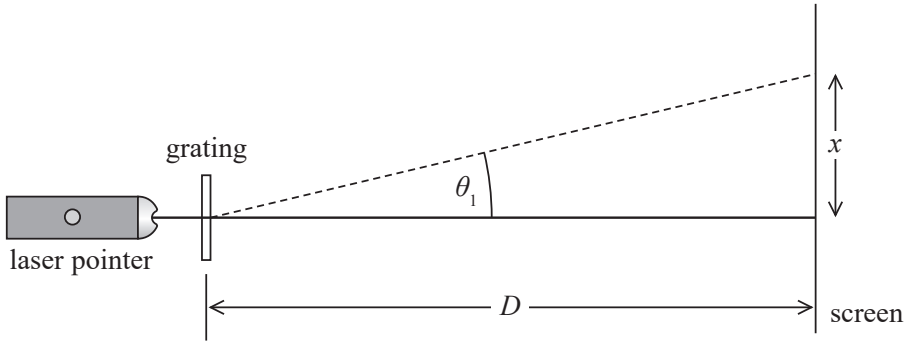
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(Total for Question 10 = 7 marks)

1 A student used a laser pointer to direct monochromatic light normal to the plane of a diffraction grating as shown.



A diffraction pattern was produced on the screen. The distance between the first order maximum and the central maximum of the diffraction pattern was x. The distance between the diffraction grating and the screen was D.

(a) The diffraction grating had 300 lines per mm.
The laser pen was marked with $\lambda = 520\,\text{nm}$.

Determine whether the spacing of the diffraction pattern was consistent with these values.

$x = 43.5\,\text{cm}$
$D = 2.75\,\text{m}$

(4)

(b) The student wrote the following conclusion:

"The value of x was measured with a metre rule. A metre rule has a precision of 0.1 cm, so this value was determined with a high degree of accuracy."

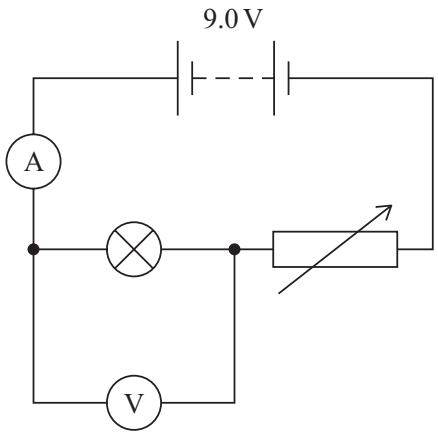
Comment on this conclusion.

(3)

(Total for Question 1 = 7 marks)

1 A student investigated the variation of current with applied potential difference (p.d.) for a filament bulb. Under normal working conditions the potential difference across the bulb is 3.0 V.

(a) The circuit diagram shows the circuit the student used.



Comment on the suitability of the student's circuit.

(3)

(b) When the p.d. across the bulb was 3.0 V, the student recorded a value of 1.29 A for the current.

In his conclusion he stated

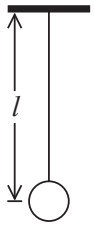
> This will give an accurate value for the working resistance, as the value of current is precise.

Assess the validity of the student's statement. You do not need to carry out a calculation.

(4)

(Total for Question 1 = 7 marks)

5 A student is using a simple pendulum to determine a value for the acceleration of free fall g.



(a) She measures the length l of the pendulum four times with a metre rule and records the following values.

l / cm			
l_1	l_2	l_3	l_4
85.5	86.0	87.5	85.5

She calculates the mean length l_m of the pendulum using the following method:

$$l_m = \frac{85.5 + 86.0 + 87.5 + 85.5}{4} = 86.1 \text{ cm}$$

(i) Calculate a more accurate value for l_m.

(2)

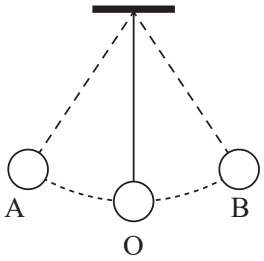
l_m = ...

(ii) Determine the time period of the oscillations of this pendulum, using your calculated value for l_m.

(2)

Time period of oscillations = ...

(b) She sets the pendulum into oscillations with small amplitude and uses a stopwatch to determine the time period.



The student releases the pendulum at A and simultaneously starts the stopwatch. She measures the time taken for 5 oscillations and divides the value by 5. She repeats the procedure twice and calculates a mean time period.

Explain two modifications to the student's method that would improve the value obtained for the time period.

(4)

(Total for Question 5 = 8 marks)

2 A student used a Geiger-Müller (GM) tube to determine the activity of a radium source. Radium emits α, β, and γ radiation.

He positioned the source 20 cm from the GM tube, as shown, and recorded the count for 1 minute. He repeated the measurement and calculated a mean count.



The student recorded the following results.

Count 1	Count 2	Mean count
183	178	181

(a) Criticise the student's method for determining the count at this position.

(3)

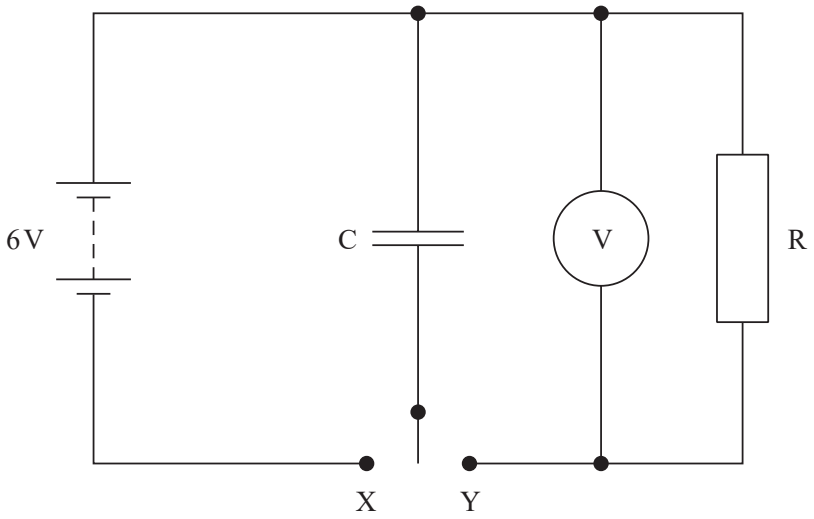
(b) From his results the student determined that the activity of the source was 3.0 Bq.

Comment on his value for the activity of the source.

(5)

(Total for Question 2 = 8 marks)

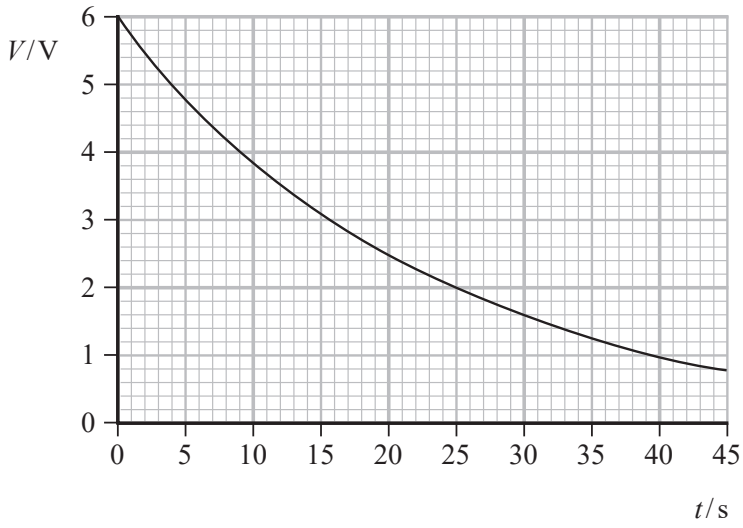
8 A student investigated the discharge of a capacitor C through a resistor R using the circuit shown.



The student used the switch to connect C to X to charge the capacitor. She then connected C to Y to discharge the capacitor through R.

As the capacitor discharged, she recorded values of the potential difference V across C and corresponding values of time t. She used a stopwatch to measure t.

The student used her results to plot the following graph.



(a) The capacitor was marked 220 μF ± 20%.

Deduce whether the student's data give a value of capacitance within the stated range.

$R = 82\,\text{k}\Omega$

(5)

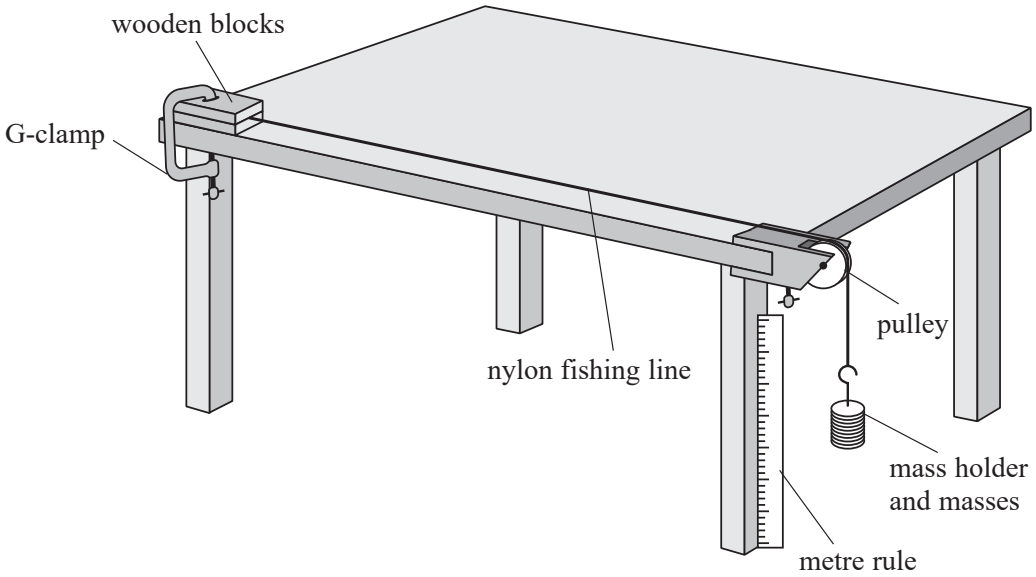
(b) The student suggested that her results would have been more accurate if she had used a data logger to record the data.

Assess the student's suggestion.

(3)

(Total for Question 8 = 8 marks)

1 A student stretched a length of nylon fishing line using the apparatus shown below.



(a) The nylon fishing line was stretched by adding masses to the mass holder. The positions of the bottom of the mass holder were measured as masses were added. For each mass, the extension of the nylon fishing line was calculated. The student recorded the results, as shown in the table.

Mass / kg	Extension / cm
0.05	0.4
0.1	0.8
0.25	2.1
0.5	3.9
0.75	6.0
1.0	7.2

Criticise the recording of these results.

(2)

.....

.....

.....

.....

(b) Describe how the extension of the nylon fishing line could have been determined as accurately as possible.

(3)

(c) The strain for the nylon fishing line at its yield point is 0.04

(i) State what is meant by yield point.

(1)

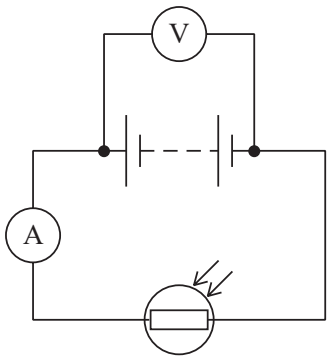
(ii) The original length of the nylon fishing line was 2.00 m.

Determine whether the fishing line was stretched beyond its yield point.

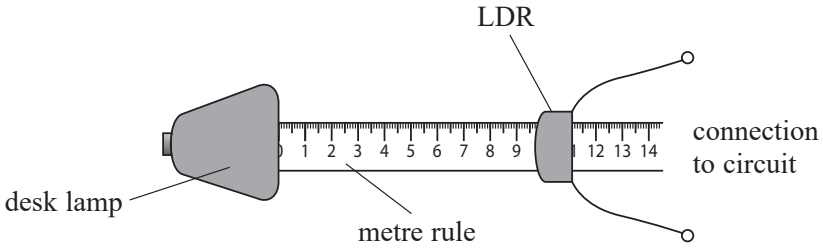
(2)

(Total for Question 1 = 8 marks)

9 A student carried out an experiment with a light dependent resistor (LDR). He connected the LDR in series with an ammeter and a power supply, as shown in the circuit diagram.



The student placed the LDR a known distance from a desk lamp, as shown.



The student noted the reading on the ammeter as he brought the LDR closer to the lamp.

(a) The student planned to vary the intensity of light incident upon the LDR by adjusting the distance x between the LDR and the lamp.

He thought that the intensity of light on the LDR would increase uniformly if he decreased x by equal intervals. He therefore planned to take ammeter readings as he decreased x from 20.0 cm to 10.0 cm in equal intervals.

(i) Criticise the student's plan for data collection.

(3)

(ii) Explain one precaution that the student should take to ensure that results are accurate.

(2)

(b) Explain why the ammeter reading increased as the LDR was brought closer to the lamp. Your answer should include reference to the charge carriers in the LDR.

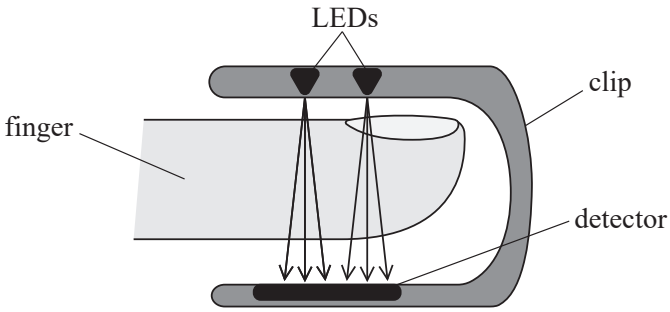
(3)

(Total for Question 9 = 8 marks)

5 An oximeter is a device used in hospitals to monitor the oxygen level in a patient's blood.

In an oximeter, two light-emitting diodes (LEDs) are mounted opposite light sensors in a clip and attached to the patient's finger. One of the LEDs produces red light and the other produces infrared.





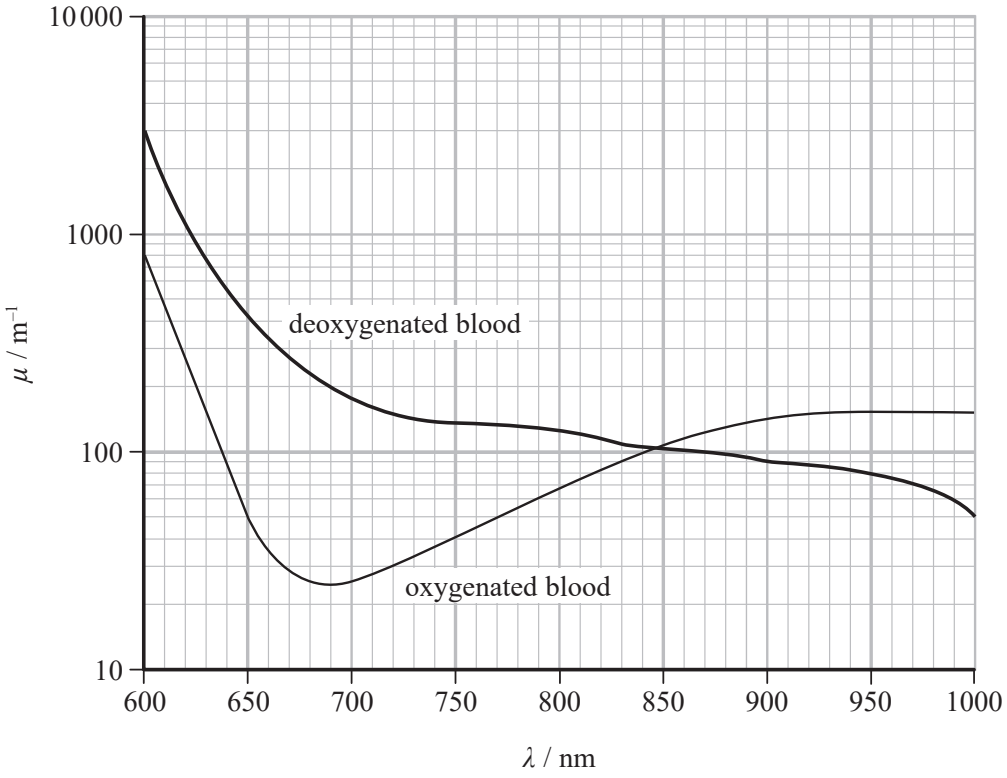
The intensity I of electromagnetic radiation received by the detector, after passing through a thickness x of blood, is given by

$$I = I_0 e^{-\mu x}$$

where I_0 is the intensity that would have been received if the blood were not present and μ is the attenuation coefficient of blood.

The red LED emits visible light of wavelength 650 nm and the infrared LED emits infrared of wavelength 950 nm.

The graph shows how μ varies with wavelength λ for oxygenated blood and deoxygenated blood.



(a) I_0 for the infrared LED is $1.8\,W\,m^{-2}$.

Calculate I for the infrared after passing through 1.4 mm of oxygenated blood.

(3)

$I =$ .....

(b) The oximeter determines I/I_0 the fraction of radiation transmitted at each wavelength.

Deduce whether I/I_0 will be smaller for the red or the infrared radiation if the blood is deoxygenated.

(3)

It is suggested that ambient light could affect the readings produced by the oximeter.

Halogen lamps have a filament temperature of 3200 K.

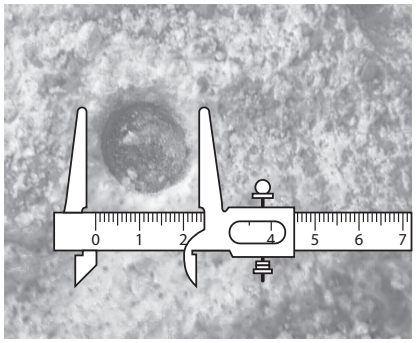
(c) Deduce whether the light from such a lamp would have a significant effect on the oximeter readings.

(3)

(Total for Question 5 = 9 marks)

12 Impact craters are formed when meteorites strike the surface of a planet. A student investigated some factors that might influence the formation of impact craters. He did this by dropping spheres of modelling clay into a tray of sand.

The diameter of the crater produced by each sphere was measured using vernier calipers as shown.



This process was repeated for spheres of different diameters.

(a) In one test, the spheres were dropped from the same height.

Determine the factor by which the kinetic energy of the sphere just before impact increases when the sphere diameter is increased from 2.0 cm to 4.0 cm.

(3)

Factor = ...

*(b) The student also dropped the spheres from different heights. His results are shown in the table.

Drop height / m	Sphere diameter / cm	Crater diameter / cm
0.30	2.0	3.6
	4.0	7.0
	6.0	6.8
0.60	2.0	4.8
	4.0	7.5
	6.0	7.3
0.90	2.0	5.6
	4.0	8.0
	6.0	8.3

The student wrote the following conclusion:

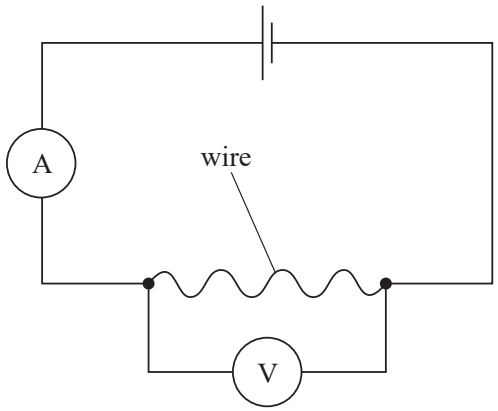
"The greater the drop height, the greater the diameter of the crater formed when a sphere hits the sand. This is because the impact velocity increases as the drop height is increased. As the speed of the sphere increases the diameter of the crater formed also increases. Also, the bigger the sphere the bigger the crater."

Assess the validity of the student's conclusion.

(6)

(Total for Question 12 = 9 marks)

12 A student carried out an experiment to determine the resistivity of a metal alloy.
The student used a wire made of the alloy and connected it in a circuit, as shown.



(a) Describe how the student could have measured the diameter of the wire accurately.

(2)

.....

.....

.....

.....

(b) The student made the following measurements:

voltmeter reading = 1.96 V
ammeter reading = 0.57 A
diameter of wire = 0.58 mm
length of wire = 83.5 cm

Calculate the resistivity of the metal alloy.

(4)

Resistivity = ...

(c) The student stated that the ammeter reading was the most significant source of uncertainty in the calculated value of resistivity.

The percentage uncertainty in the ammeter reading was 0.9%.
The percentage uncertainty in the measurement of diameter was 0.8%.
The percentage uncertainty in the measurement of length was 0.1%.
The percentage uncertainty in the voltmeter reading was 0.3%.

Assess the validity of the student's statement.

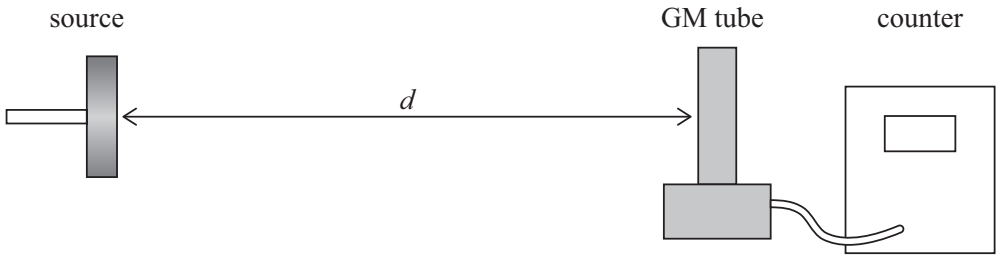
(3)

(Total for Question 12 = 9 marks)

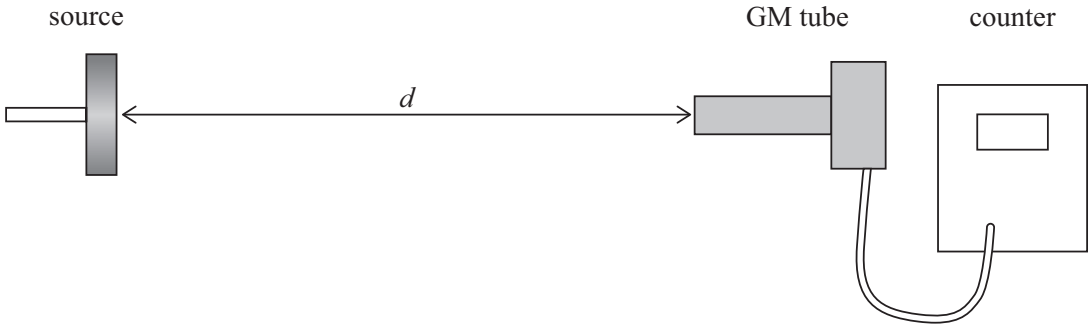
4 Two students, A and B, used a cobalt-60 source to investigate the inverse square law for a gamma radiation source. Cobalt-60 is a pure gamma emitter.

(a) The cobalt-60 source was placed in a source holder. A Geiger-Müller (GM) tube was connected to a counter and placed a short distance *d* away.

(i) Student A set up the apparatus as shown.



Student B used the same distance *d* but rotated the GM tube by 90°, as shown below.



Both students recorded the count for 2 minutes.

Deduce which set-up will lead to a smaller percentage uncertainty in the count rate.

(3)

(ii) Explain two modifications to the experimental method which would improve the accuracy of the data.

(4)

(b) Student A suggests that the investigation into the inverse square law for a gamma radiation source could be carried out successfully using a radium-226 source.

Radium-226 emits alpha and beta radiation as well as gamma radiation.

Explain **one** modification that would be necessary if a radium-226 source were to be used.

(2)

(Total for Question 4 = 9 marks)

5 Fuse wire is made of a metal that has a low melting point. The wire melts when the current exceeds a maximum value.

A student investigated how the cross-sectional area affected the current at which a wire melted. She used wires of the same length and metal, but different diameters.

The student steadily increased the current through each wire and recorded the maximum current through the wire before it melted.

(a) Describe how the student could determine an accurate value for the cross-sectional area of a wire.

(4)

(b) (i) Explain why a current in a wire causes the resistance of the wire to change.

(3)

(ii) The length of a wire does not affect the value of current at which the wire melts.

Explain why. Assume the wire behaves as a black body.

(2)

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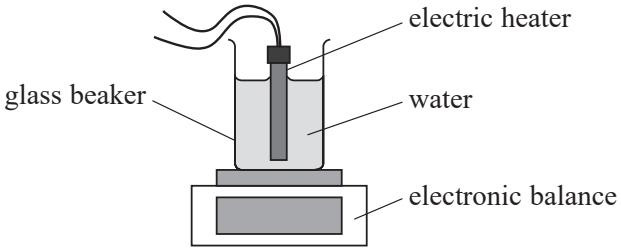
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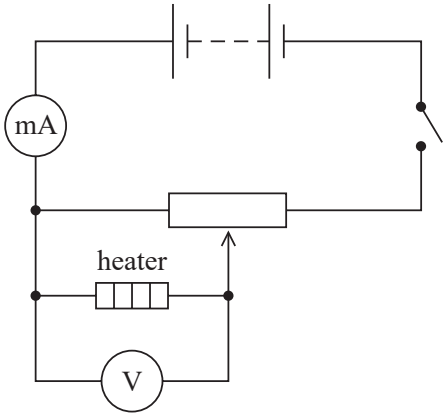
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(Total for Question 5 = 9 marks)

3 The specific latent heat of vaporisation of water can be determined using the apparatus shown.



(a) A student planned to vary the current in the heater from 0 A to 5 A. The student connected the following circuit to measure the current in the heater.



Criticise the student's circuit.

(2)

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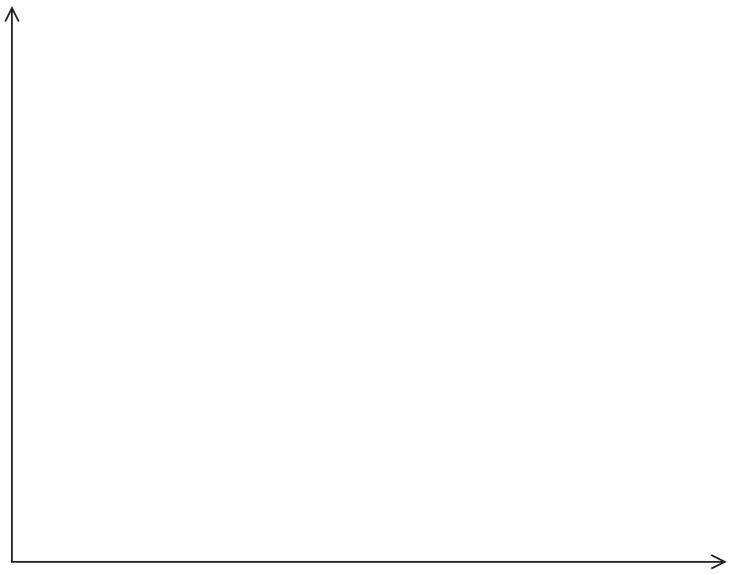
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(b) (i) The student corrected the circuit and closed the switch. He waited until the water started boiling. He started a stopwatch and recorded the readings on the balance at regular time intervals.

Sketch a graph, on the axes below, of how the readings on the balance would vary with time.

(3)



(ii) The heater was switched on for 6.0 minutes and the change in mass of water in the beaker was 7.5 g.

Calculate the specific latent heat of vaporisation of water, L.

$V = 12\,\text{V}$
$I = 4.2\,\text{A}$

(3)

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$L =$ .....

(iii) The errors in the experiment include uncertainty in the mass reading and uncertainty in reading the stopwatch, as the water boils.

Explain how another significant source of error affects the value of L obtained from the experiment.

(2)

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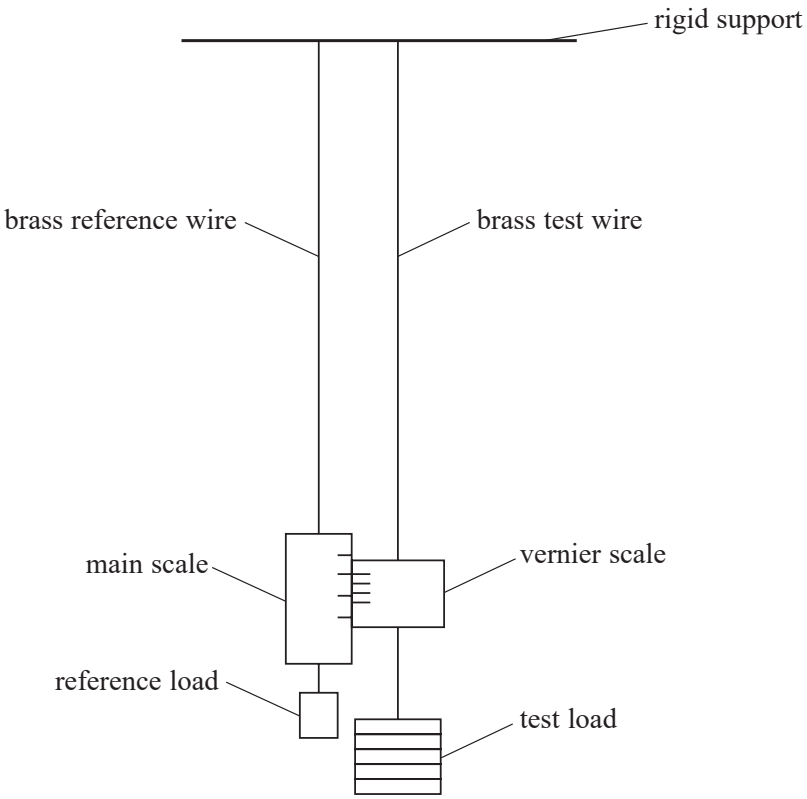
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(Total for Question 3 = 10 marks)

5 A student used the apparatus shown to determine the Young modulus of brass. Loads were added to the test wire and corresponding readings taken from the vernier scale. The test wire and the reference wire were identical.



(a) (i) Give one advantage of using a reference wire as well as a test wire.

(1)

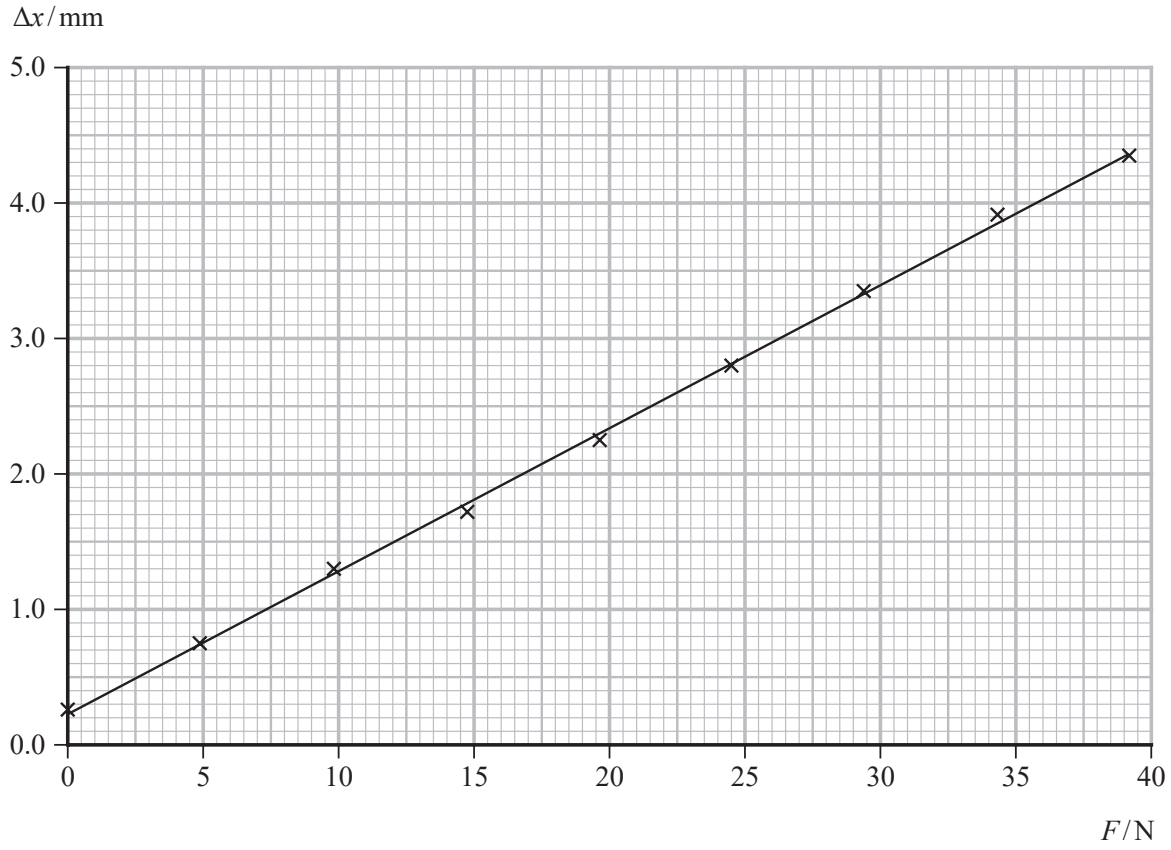
(ii) State why a reference load was applied to the reference wire.

(1)

(b) Explain why the test wire should be both long and thin.

(3)

(c) The student varied the load F on the test wire and recorded the corresponding change in length Δx from the vernier scale. The results are shown on the graph.



Determine a value for the Young modulus of brass.

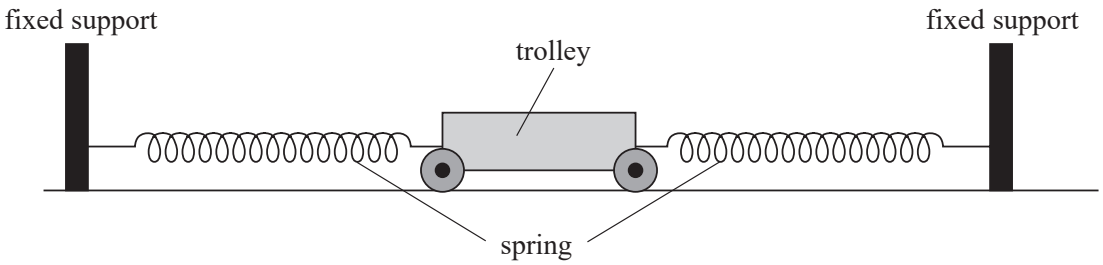
length of wire = 2.75 m
diameter of wire = 5.60×10^{-4} m

(5)

Young modulus of brass = ...

(Total for Question 5 = 10 marks)

5 A student used springs to attach a trolley between two fixed supports, as shown.



When displaced horizontally, the trolley oscillated with simple harmonic motion.

To determine the time period T of oscillation of the trolley, the student displaced the trolley from its equilibrium position and released it. As she released the trolley, she started a stopwatch. She stopped the stopwatch when the trolley had returned to its starting point.

(a) Explain how the procedure used by the student to determine T could have been improved.

(6)

(b) The mass of the trolley was M. The student added a small mass m to the trolley and determined the new value of T. She repeated the procedure for a range of values of m.

She plotted a graph of T^2 against m.

Explain how she could use her graph to determine a value for M.

(4)

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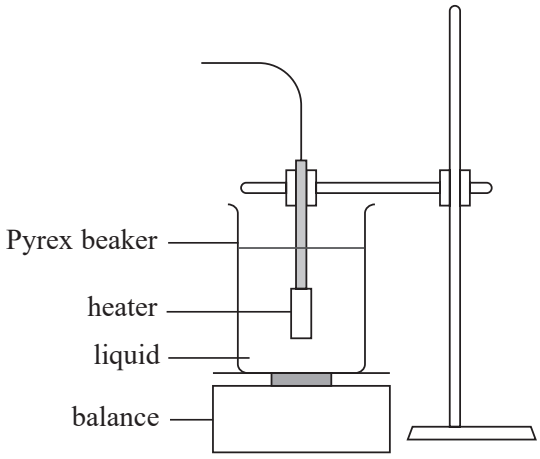
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(Total for Question 5 = 10 marks)

6 A student determined the latent heat of vaporisation of a liquid using an electrical heater to boil the liquid in a Pyrex beaker.

The apparatus used is shown below.



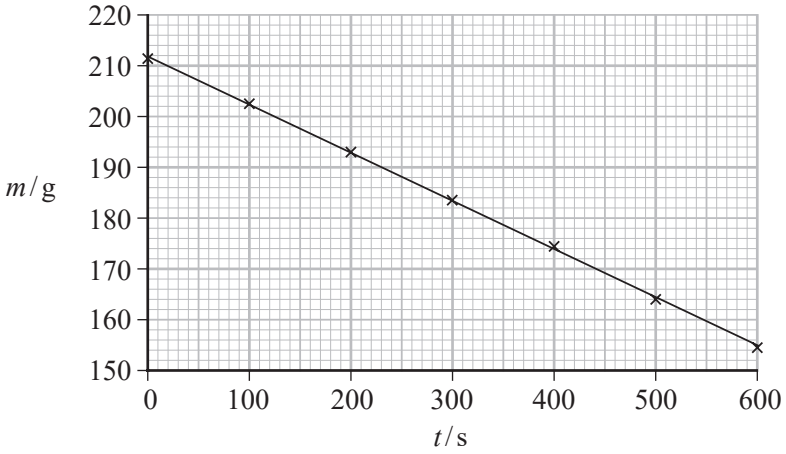
(a) She connected the heater into a circuit and took measurements of the potential difference V and the current I for the heater.

Complete the circuit diagram to show a suitable circuit.

(2)



(b) The student monitored the mass of the beaker and the liquid m over the time t for which the liquid was boiling. Her results are plotted on the graph.



The student used her graph to determine a value for the latent heat of the liquid in the beaker. She concluded that the liquid was pure water.

Liquid	Latent heat of vaporisation / MJ kg^{-1}
Pure water	2.26
Weak salt water solution	2.10
Strong salt water solution	2.00

Comment on the validity of the student's conclusion.

$V = 20.5\,\text{V}$

$I = 10.5\,\text{A}$

(7)

(c) Explain how this method might be modified to improve the accuracy of the student's conclusion.

(2)

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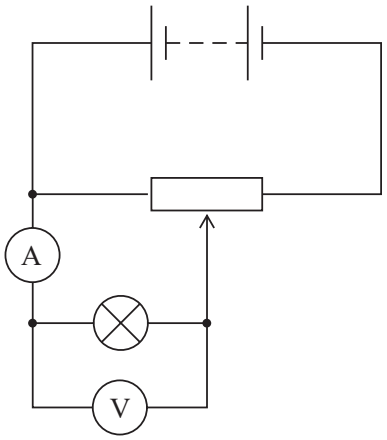
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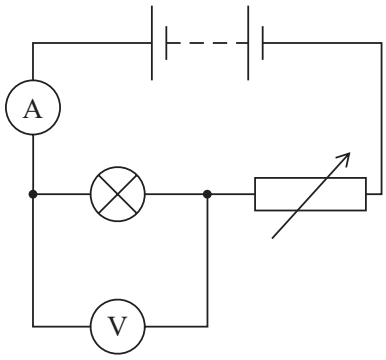
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(Total for Question 6 = 11 marks)

9 A student is planning to collect data to produce a current-potential difference graph for a filament lamp. Her teacher suggests two circuits that she could use.



Circuit 1



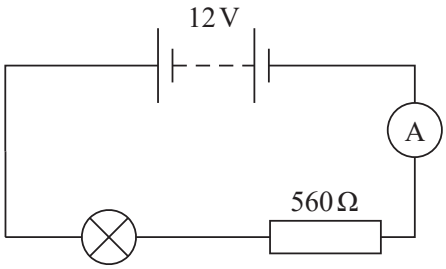
Circuit 2

Circuit 1 uses a potential divider and circuit 2 uses a variable resistor to vary the potential difference across the filament lamp.

*(a) Discuss the suitability of each circuit to collect the data.

(6)

(b) The student sets up the following circuit with the filament lamp. The battery has negligible internal resistance.



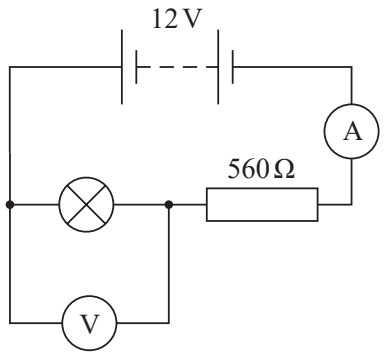
(i) The reading on the ammeter is 17.5 mA.

Calculate the value of the potential difference (p.d.) across the filament lamp.

(2)

p.d. across filament lamp = ...

(ii) When a voltmeter with a resistance of 1.5 kΩ is connected as shown, the p.d. across the filament lamp decreases.



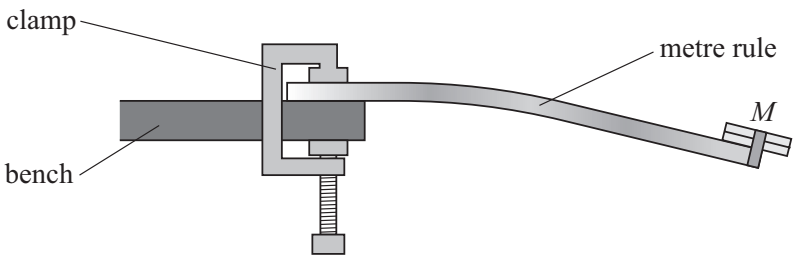
Explain why the p.d. across the filament lamp decreases.

(3)

(Total for Question 9 = 11 marks)

9 A cantilever is a beam fixed at one end.

A student made a cantilever by clamping a metre rule to a bench and attached a mass M at the free end, as shown.



The student displaced the free end through a small distance. When the free end was released, the cantilever oscillated with simple harmonic motion of period T.

(a) The student measured the time for 5 oscillations with an electronic stopwatch. This was repeated twice.

(i) Explain **one** modification to the apparatus which would improve the accuracy of the data the student obtained.

(3)

(ii) Explain **one** modification to the student's method which would reduce the percentage uncertainty in her measurement of T.

(2)

(b) The length of the metre rule overhanging the bench was L. The period of oscillation T is related to L, M and the Young modulus E of the wood of the metre rule by the expression

$$T^2 \propto \frac{ML^3}{E}$$

The student repeated the timing measurements for a half-metre rule.

The half-metre rule had the same added mass M, width and thickness as the metre rule.

The metre rule was made from wood of Young modulus E_1, and the half-metre rule was made from wood of Young modulus E_2.

The student collected the following data.

			Time for 5 oscillations		
	Young modulus	**L / m**	**t_1 / s**	**t_2 / s**	**t_3 / s**
Metre rule	E_1	0.95	14.69	14.64	14.76
Half-metre rule	E_2	0.45	5.33	5.40	5.24

The table below gives the Young modulus values of various types of wood.

Type of wood	**Cedar**	**Spruce**	**Pine**
Young modulus / GPa	7.7	9.6	10.1

Deduce the type of wood each rule is made from.

(6)

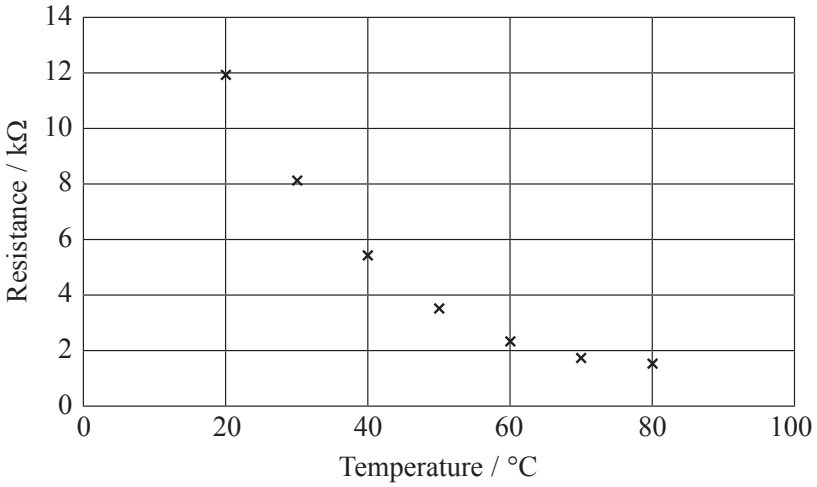
(Total for Question 9 = 11 marks)

12 A student wants to investigate how the resistance R of a negative temperature coefficient thermistor varies with its temperature T.

(a) Write a set of instructions that the student could follow and include one safety precaution.

(6)

(b) The following graph was plotted from the results of another student's experiment for the same topic.



Give two modifications to the experimental procedure that could improve these results.

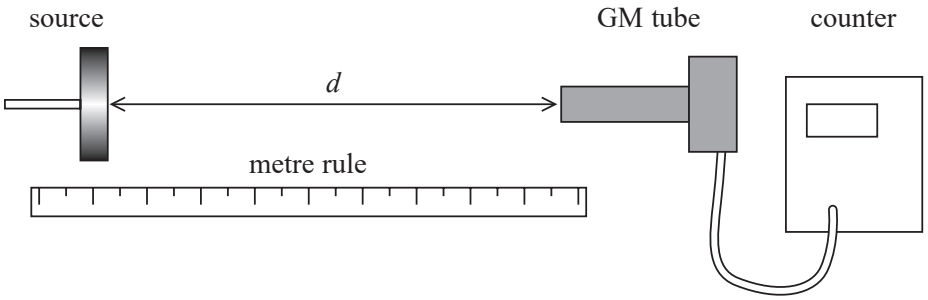
(2)

(c) Explain, in terms of particle behaviour, why the resistance of the thermistor decreases as temperature increases.

(4)

(Total for Question 12 = 12 marks)

10 A student investigated the way in which gamma radiation spreads out from a source. He placed a cobalt-60 source in a source holder and set up a Geiger-Müller (GM) tube a short distance *d* away. He connected the GM tube to a counter as shown.

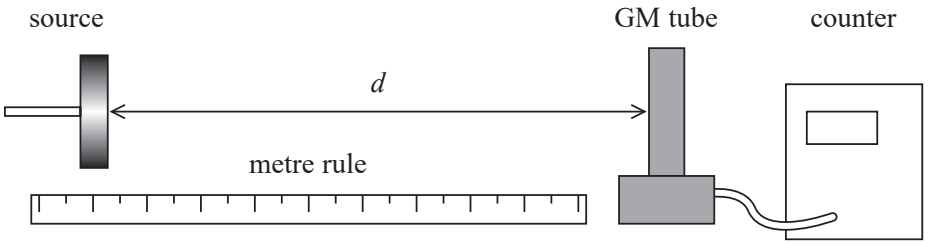


The student recorded the count for 2 minutes.

(a) Describe how to determine the corrected count rate from the source.

(2)

(b) His teacher turned the GM tube through 90° so that the side of the tube faced the source as shown below.



(i) Explain why this arrangement could lead to more accurate data.

(2)

(ii) Explain another modification to the experimental method which would improve the accuracy of the data.

(2)

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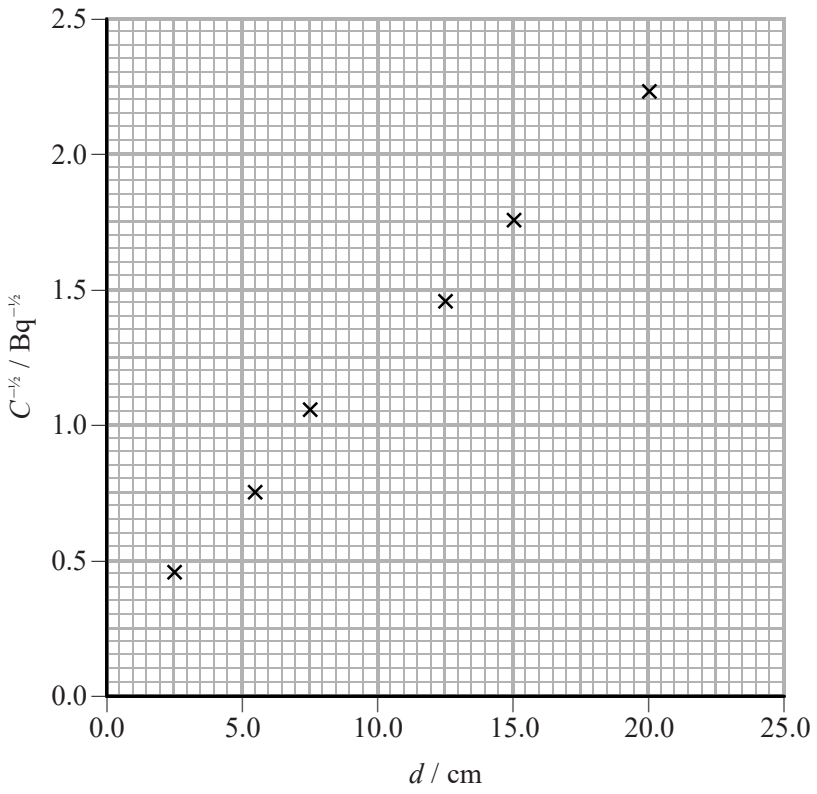
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(c) The variation in the intensity of gamma radiation with distance from a point source should obey an inverse square law. If this is the case, then the count rate C should vary with d according to the equation

$$C = \frac{K}{4\pi d^2}$$

where K is a constant.

The student plotted $\frac{1}{\sqrt{C}}$ against d and obtained the following graph.



(i) Draw a line of best fit on the graph.

(1)

(ii) The student concluded that the graph was consistent with the gamma radiation intensity obeying an inverse square law.

Discuss the extent to which the data obtained supports the student's conclusion.

(4)

(d) It is suggested that the investigation into the way in which gamma radiation spreads out from a source, using the apparatus as shown in (b), could be carried out successfully using a radium-226 source.

Radium-226 emits α, β and γ radiation.

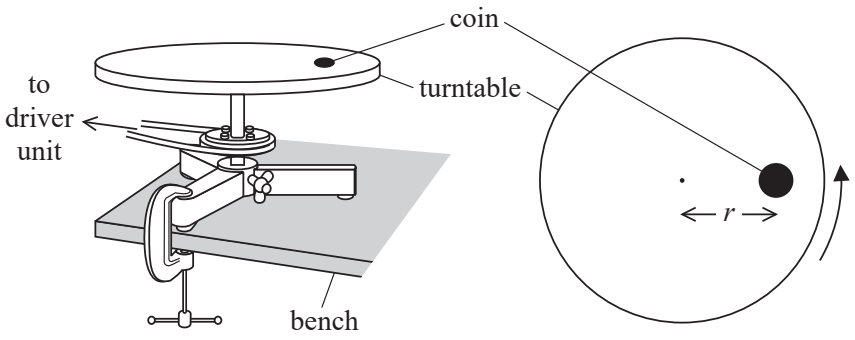
Justify this suggestion.

(2)

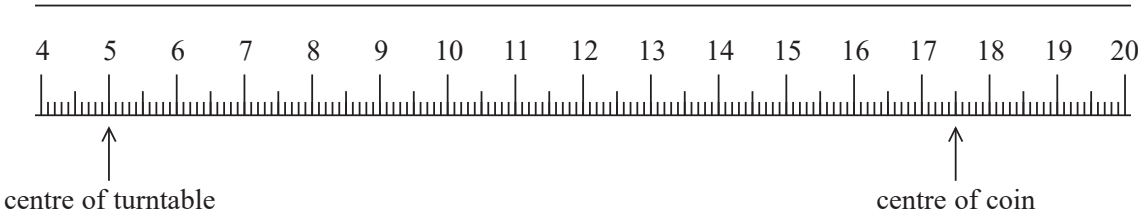
(Total for Question 10 = 13 marks)

3 A student was investigating the forces involved in circular motion.

He placed a small coin on a horizontal turntable as shown. The turntable was connected to a driver unit so that it could be rotated at a constant rate.



(a) The student measured the distance r between the centre of the turntable and the centre of the coin, with a metre rule as shown.



Explain why the percentage uncertainty in the value of r is about 1%.
Your answer should include a calculation.

(3)

(b) The student switched on the driver unit and increased the rate of rotation until the coin slid off the turntable. He read the angular velocity ω of the turntable from a digital display on the driver unit. He then replaced the coin in the original position on the turntable and repeated the procedure.

His results are shown.

ω / rad s^{-1}				
0.125	0.112	0.118	0.123	0.116

(i) The student used the results to calculate a mean value of ω.

State the purpose of calculating a mean.

(1)

.....

(ii) Calculate the percentage uncertainty in the mean value of ω.

(3)

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Percentage uncertainty = ...

(iii) The student used ω and r to calculate the centripetal acceleration of the coin at the instant it started to slide.

Calculate the percentage uncertainty in this centripetal acceleration.

(3)

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Percentage uncertainty = ...

(c) The student repeated the procedure with different values of r.

Explain how the value of ω at which the coin started to slide varied as r increased.

(3)

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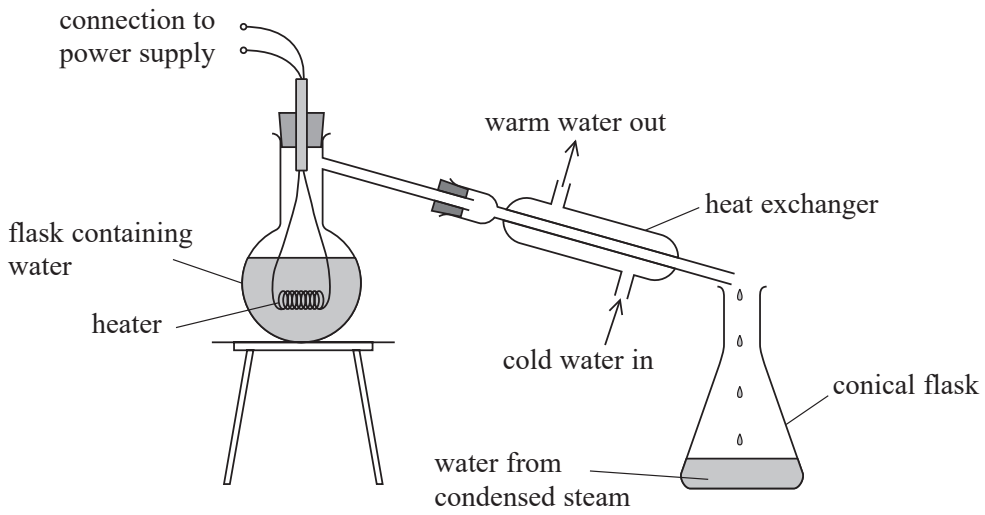
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(Total for Question 3 = 13 marks)

8 The apparatus shown can be used to determine a value for the specific latent heat of vaporisation of water.



(a) In one experiment the current in the heater was 8.20 A, and the potential difference across the heater was 230 V.

(i) Show that the power of the heater was about 2 kW.

(2)

(ii) There was 0.655 kg of water in the flask at an initial temperature of 22.5 °C. The heater was switched on, and the water in the flask was heated to boiling point.

Calculate the minimum time taken for the water to be heated to 100.0 °C.

specific heat capacity of water = 4190 J kg^{-1} K^{-1}

(3)

Minimum time taken for water to be heated = ...

(b) The heater was left on and water continued to boil in the flask. The water was allowed to boil for a few minutes. The conical flask was then placed under the heat exchanger and water was collected in it.

(i) Give a reason why the water was left boiling for a few minutes before the conical flask was put in place.

(1)

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(ii) Water with a mass of 95.0 g was collected in a time of 125 s.

Calculate the rate of energy transfer in the heat exchanger.

specific latent heat of vaporisation of water = $2.26 \times 10^6\,J\,kg^{-1}$

(3)

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Rate of energy transfer in the heat exchanger = ...

(iii) Discuss your answers to (a)(i) and (b)(ii).

(3)

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(c) State how the apparatus could be modified to minimise the effect of a significant source of error.

(1)

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(Total for Question 8 = 13 marks)

12 A student investigated the properties of metal wires.

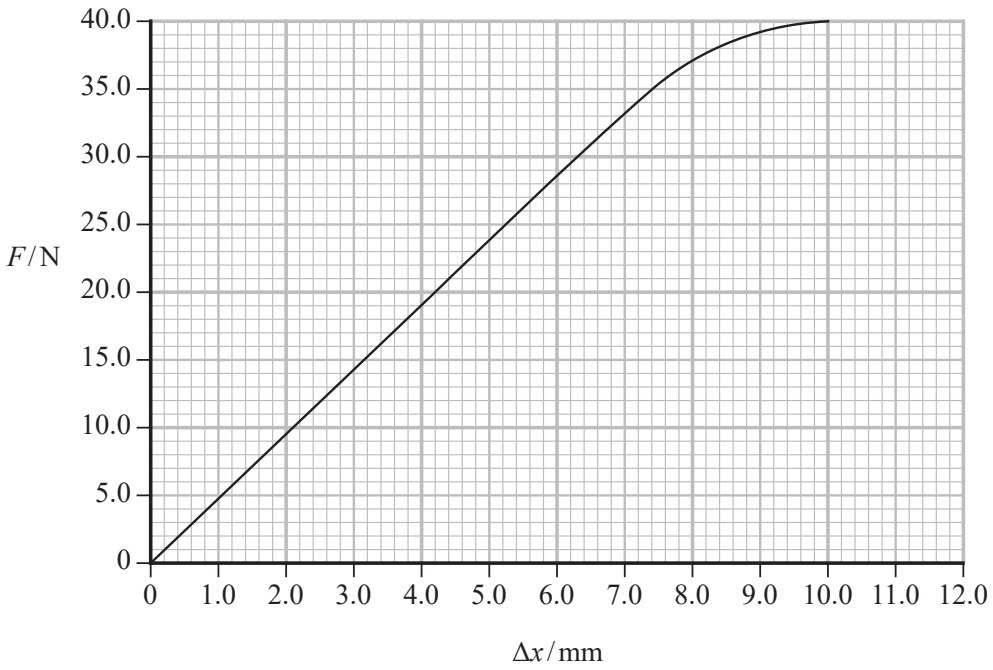
(a) Describe how the student should determine the diameter of a wire.

(3)

(b) The student applied increasing force F and determined the corresponding extensions Δx of the wire.

The force was applied in increments of 5 N, up to a maximum value of 40 N.

The student plotted a graph of F against Δx, as shown.



The Young modulus E of the material of the wire is given by the expression

$$E = \text{gradient} \times \frac{x}{A}$$

where A is the cross-sectional area of the wire and x is the original length of the wire.

(i) Derive the expression

$$E = \text{gradient} \times \frac{x}{A}$$

(2)

(ii) The values of the Young modulus for some metals are shown.

Metal	Young modulus / GPa
aluminium	67
copper	117
steel	184
tin	47

Deduce which metal the student's wire was made from.

$x = 3.00\,\text{m}$
$A = 1.14 \times 10^{-7}\,\text{m}^2$

(4)

(iii) The student repeated measurements of force and extension using a thinner wire of the same metal and length. He changed the values of the force he applied to the wire.

Explain **two** changes that the student should make to the values of the force he applied to the wire.

(4)

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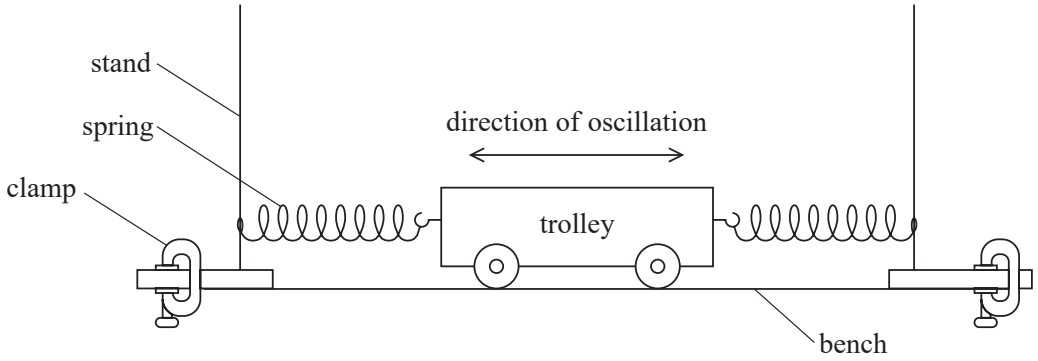
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(Total for Question 12 = 13 marks)

6 A student investigated the horizontal oscillations of a trolley between two springs, using the apparatus shown.



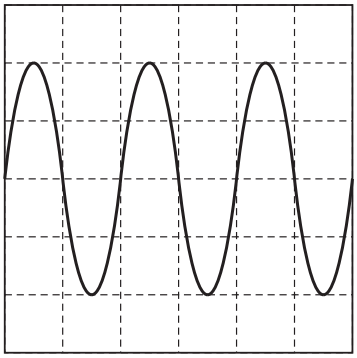
The student displaced the trolley from its equilibrium position. She then released the trolley and started a stopwatch. She stopped the stopwatch when the trolley had completed one oscillation.

(a) Describe how the method used by the student could be improved to determine a more accurate value of the time period.

(4)

(b) The student displaced the trolley 6.0 cm from the equilibrium position.
She recorded the velocity of the oscillating trolley using a sensor connected to a data logger.

The output from the data logger is shown below.



The time-base of the data logger output was set to 250 ms div^{-1}.

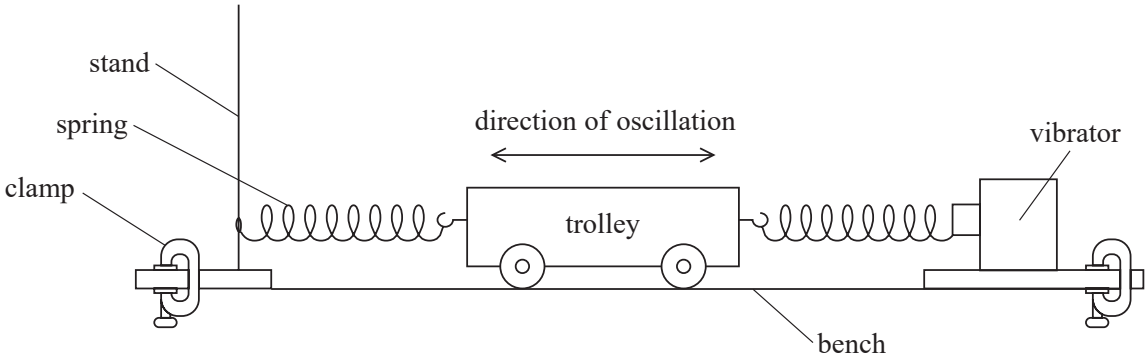
Determine the maximum velocity of the trolley.

(5)

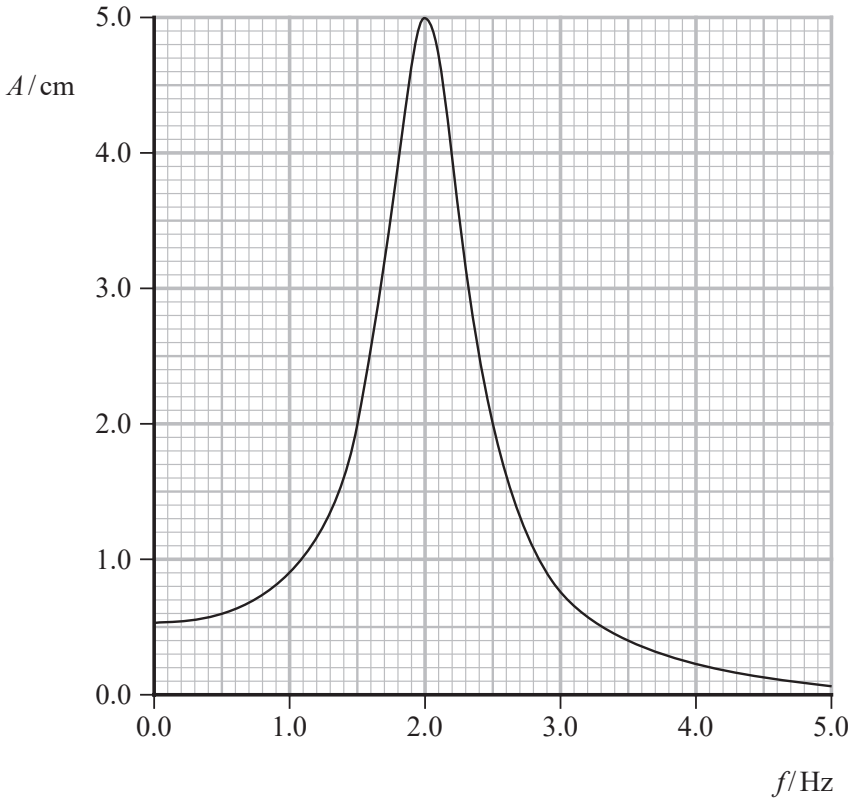
Maximum velocity of trolley = ...

(c) The student modified the apparatus so that the trolley was driven into oscillation by a vibrator, as shown.

A sensor connected to a data logger recorded the amplitude A of the oscillations.



The graph shows how A varied as the student increased the frequency f of the oscillations.



(i) Explain the shape of the graph.

(4)

(ii) Determine the effective spring constant k of the oscillating trolley system.

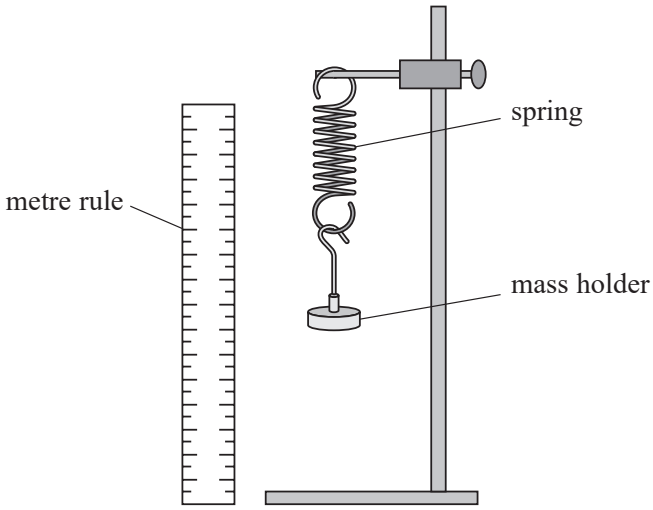
mass of trolley = 0.87 kg

(2)

k = ...

(Total for Question 6 = 15 marks)

10 A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached as shown.



(a) The student measured the length of the spring as he added masses to the holder. The rule was held as shown to measure the distance between the top and bottom coils of the spring. He determined the extension for each value of total mass on the holder. He did this by subtracting the original length of the spring from each extended length.

(i) Explain whether this method would produce accurate values for the extensions of the spring.

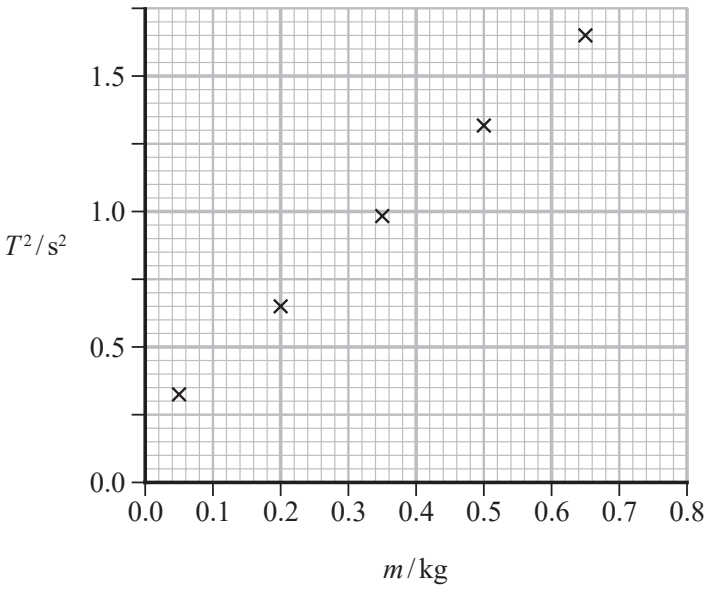
(4)

(ii) Explain how the student could modify his method in order to obtain more accurate values for the extensions of the spring.

(5)

(b) In another experiment, the student displaced the mass vertically each time a mass was added to the spring. He used a stopwatch to determine the period of vertical oscillations of each mass.

The student used his data to plot a graph of T^2 against m as shown.



The student expected the graph to be a straight line through the origin. He thought that there may be systematic error due to reaction time.

(i) Give an example of another possible systematic error in this experiment.

(1)

.....

.....

(ii) Another student suggests that to reduce the uncertainty in the value for the period, a data logger connected to a light gate could be used to measure time.

Comment on the student's suggestion.

(3)

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(iii) Determine a value for the stiffness of the spring.

(3)

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Stiffness of spring = ...

(c) When determining the period of oscillation for each mass, the student measured the time for 20 oscillations. He repeated this measurement to obtain a mean time for 20 oscillations.

Explain how the student's procedure contributed to the accuracy of the measurement.

(3)

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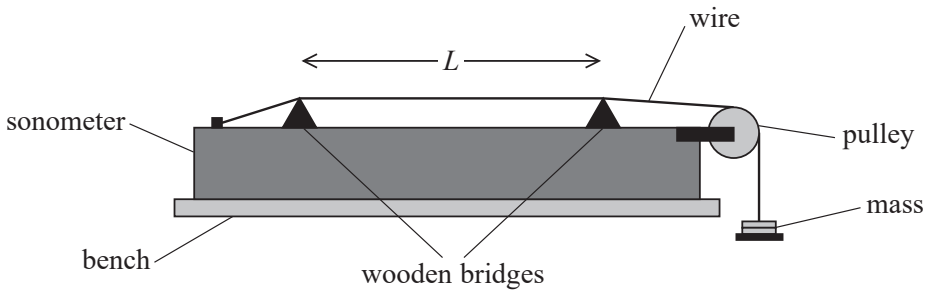
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(Total for Question 10 = 19 marks)

13 A student used a sonometer to investigate the properties of a stretched wire. The sonometer is a long hollow wooden box.

A steel wire is attached to one end of the box and rests on two wooden bridges. The wire is placed under tension T by hanging a mass from the end of the wire, as shown.



The student placed the base of a vibrating tuning fork in contact with the wire, at one of the bridges. This set the wire into oscillation. He adjusted the position of the other bridge until a single-loop standing wave was produced on the wire between the bridges.

(a) Explain how an antinode is produced at the mid-point of the wire between the bridges.

(3)

(b) The student repeated this for a series of tuning forks with different frequencies f. For each fork he measured the distance L between the bridges.

The steel wire, of mass per unit length μ, was placed under tension T by hanging a mass of 2.10 kg from the end of the wire.

(i) State one safety precaution that should be taken when carrying out the investigation.

(1)

.....

(ii) The student plotted a graph of L^2 against $1/f^2$.

Show that the gradient of this graph is equal to $\frac{T}{4\mu}$

(3)

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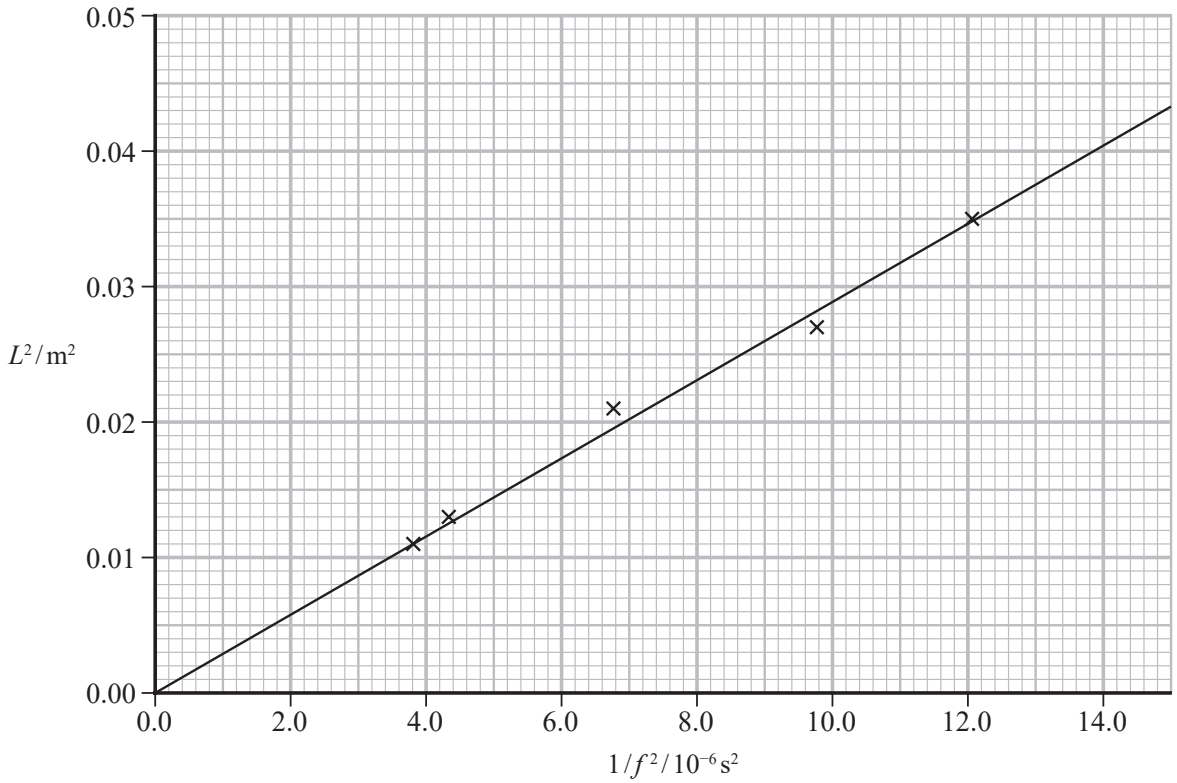
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(iii) The student's graph is shown below.



The value of μ for different standard wire gauge (SWG) steel wire is shown in the table.

SWG	μ / g m^{-1}
22	3.15
24	1.95
26	1.31

Deduce which wire the student used in the investigation.

(4)

(c) The student then found a value of μ for a brass wire, using a different method.

(i) He measured the diameter d of the wire using a micrometer.

Explain one technique the student should use when measuring d.

(2)

(ii) The student obtained the following data.

d / mm			
0.55	0.59	0.57	0.58

The stated value of μ for the brass wire used by the student was $2.14 \times 10^{-3}\,\text{kg m}^{-1}$.

Deduce whether the student's data supports this value for μ.

density of brass = $8700\,\text{kg m}^{-3} \pm 200\,\text{kg m}^{-3}$

(6)

(Total for Question 13 = 19 marks)

SUB-TOPIC 1.5

GRAPHS, LINEARISATION AND DATA ANALYSIS

Sub-topic 1.5 · 16 questions · 162 marks · lowest tariff first

2 The velocity of a wave on a string is given by $v = \sqrt{\frac{T}{\mu}}$ where T is the tension in the string and μ is a constant.

Which of the following pairs of variables, if plotted, would produce a straight line graph?

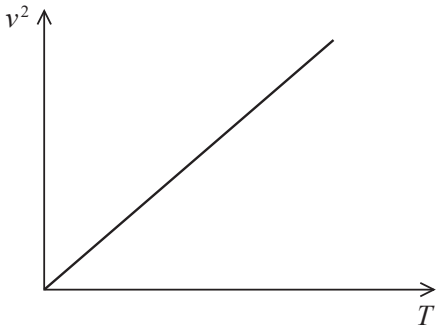
	x-axis	*y*-axis
☒ **A**	T	$\sqrt{v}$
☒ **B**	v	T
☒ **C**	$\frac{1}{v}$	T
☒ **D**	$\sqrt{T}$	v

(Total for Question 2 = 1 mark)

Questions 7 and 8 refer to an experiment to investigate stationary waves on a string.

A string of length l, fixed at both ends, is placed under tension T and plucked. The fundamental frequency f of the vibrating string is measured and the speed v of the wave on the string is calculated.

8 Corresponding values of v^2 against T are plotted. A straight line graph is obtained, as shown.



Which of the following expressions for the mass per unit length μ of the string is correct?

☒ **A** μ = gradient

☒ **B** $\mu = \sqrt{\text{gradient}}$

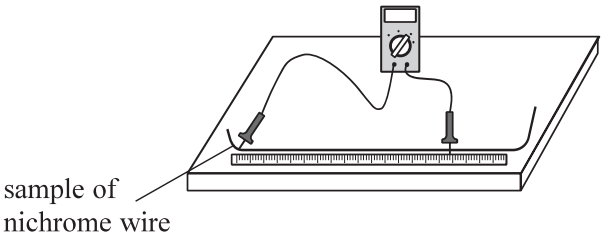
☒ **C** $\mu = \dfrac{1}{\text{gradient}}$

☒ **D** $\mu = \dfrac{1}{\sqrt{\text{gradient}}}$

(Total for Question 8 = 1 mark)

Questions 6 and 7 refer to the information below.

An ohmmeter was used to measure the resistance R of a length l of nichrome wire as shown. This was then repeated for different values of l.



6 The diameter of the wire was measured and the cross-sectional area A of the wire calculated.

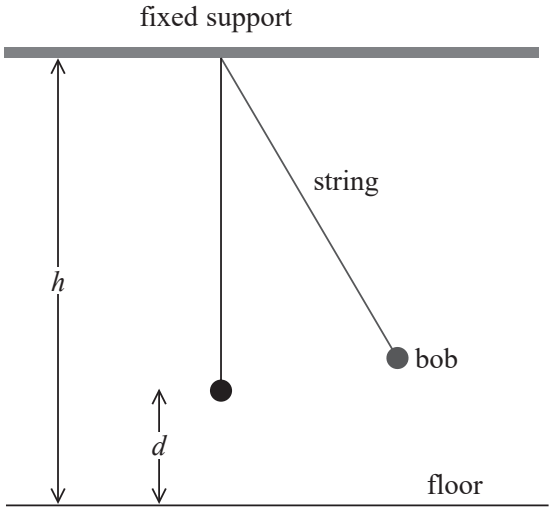
A graph was plotted. The gradient of the graph was equal to the resistivity of nichrome.

Which row of the table shows the quantities which were plotted on the y-axis and the x-axis?

		***y*-axis**	***x*-axis**
☒	**A**	l	RA
☒	**B**	lA	R
☒	**C**	R	Al
☒	**D**	RA	l

(Total for Question 6 = 1 mark)

3 A student carried out an experiment with a pendulum hung from a fixed support. The fixed support was a distance h above floor level as shown.



As the student was unable to measure the length of the pendulum directly, she measured the distance d from the bob to the floor.

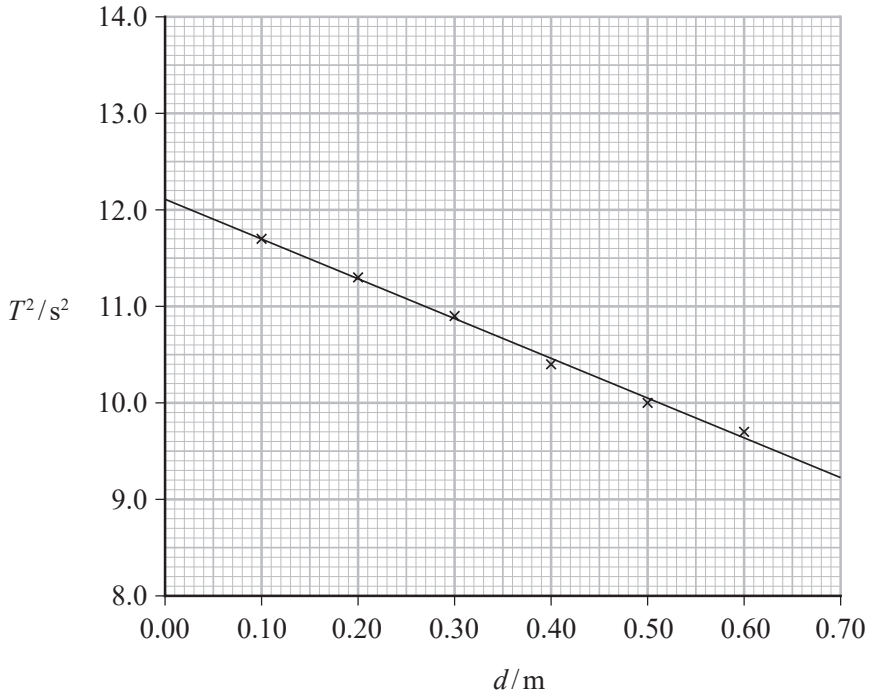
(a) To determine the period T of the pendulum, the student used the following method:

- release the bob from its highest position and start a stopwatch
- stop the stopwatch when the bob reaches the same position again.

Criticise the student's method for measuring the period.

(2)

(b) The student used her data to plot a graph of T^2 against d as shown below.



Determine a value for the acceleration due to gravity g.

(5)

$g =$ .....

(Total for Question 3 = 7 marks)

12 A student carries out an experiment using a guitar string. She investigates the effect of varying the tension in the guitar string on the frequency of sound produced when the string is plucked.

(a) Describe a method of varying and measuring the tension in the string.

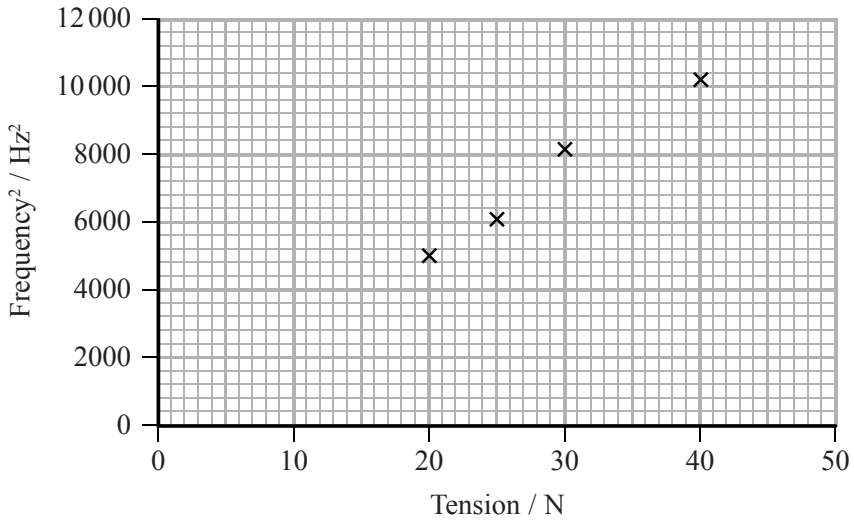
(2)

(b) The student records the following data and plots a graph.

Tension / N	20	25	30	35	40
Frequency / Hz	70	78	90	95	101
Frequency^2 / Hz^2	4900	6084	8100		10201

Complete the table and graph.

(3)



(c) The student reads that guitar strings have a mass per unit length of between 0.4×10^{-3} kg m^{-1} and 7×10^{-3} kg m^{-1}.

Determine whether the guitar string used in this experiment lies within this range.

length of string vibrating = 0.40 m

(5)

(Total for Question 12 = 10 marks)

9 The Beaufort scale is used to describe wind intensity. On this scale the average wind speed v increases with the Beaufort scale value B.

The relationship between v and B is given by

$$v = kB^p$$

where k and p are constants.

(a) Explain why a graph of $\log v$ against $\log B$ should give a straight line.

(2)

(b) The table gives some values of v and corresponding values of B.

v / m s^{-1}	B		
2.00	1		
10.0	3		
21.5	5		
36.0	7		
50.5	9		
68.0	11		

(i) Plot a graph of $\log v$ against $\log B$ on the grid opposite.
Use the columns provided to show any processed data.

(5)

(ii) Determine the values of p and k.

(3)

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$p =$ .....

$k =$ .....

(Total for Question 9 = 10 marks)

11 A student used steel ball bearings falling through a viscous liquid to investigate the relationship between the terminal velocity v of a ball bearing and its radius r.

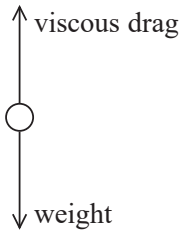
(a) The student used ball bearings with different radii.

Describe how the student can make measurements of the ball bearing to determine its radius.

(3)

(b) A free body force diagram for a ball bearing of radius 5.00 mm falling through the liquid is shown. The upthrust on the ball bearing has been ignored.

Diagram **NOT** to scale



(i) Show that the weight of a ball bearing with a radius of 5.0 mm is about 4×10^{-2} N.

density of steel = $8.0 \times 10^{3}\,\text{kg}\,\text{m}^{-3}$

(3)

(ii) Calculate the terminal velocity of the ball bearing as it falls through the liquid. You may ignore the upthrust on the ball bearing.

viscosity of liquid = 1.8 Pa s

(2)

Terminal velocity = ...

(c) Explain how the student can ensure that Stokes' law will apply to the ball bearings falling through the viscous liquid.

(2)

(Total for Question 11 = 10 marks)

9 The majority of stars in the universe are thought to be main sequence stars. For such stars the luminosity increases with the mass of the star.

(a) It is suggested that the relationship between luminosity and mass is of the form

$$L = L_{\text{Sun}} M^{p}$$

where L = luminosity, M = (mass of star / mass of the Sun) and L_{Sun} and p are constants.

Explain why a graph of log L against log M would give a straight line.

(2)

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(b) The table shows data for a range of main sequence stars.

$L/10^{25}$ W	M		
3.63	0.557		
469	1.88		
5920	3.52		
40 800	5.85		
294 000	9.72		

(i) Plot a graph of log L against log M. You may use the columns provided to show any processed data.

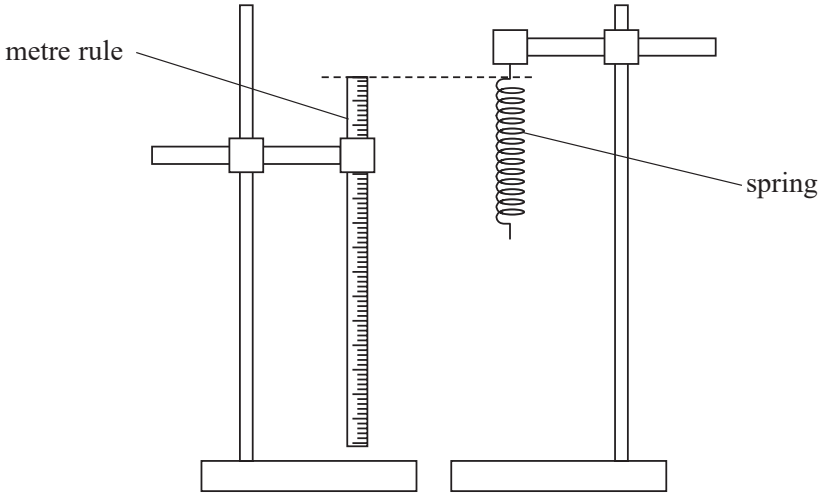
(5)

(ii) Determine values for p and L_{Sun} and hence state the mathematical relationship between L and M.

(4)

(Total for Question 9 = 11 marks)

16 A spring was hung from a clamp, as shown.



(a) A student used the metre rule to measure the unstretched length of the spring.

Describe how the student could make this measurement as accurate as possible.

(2)

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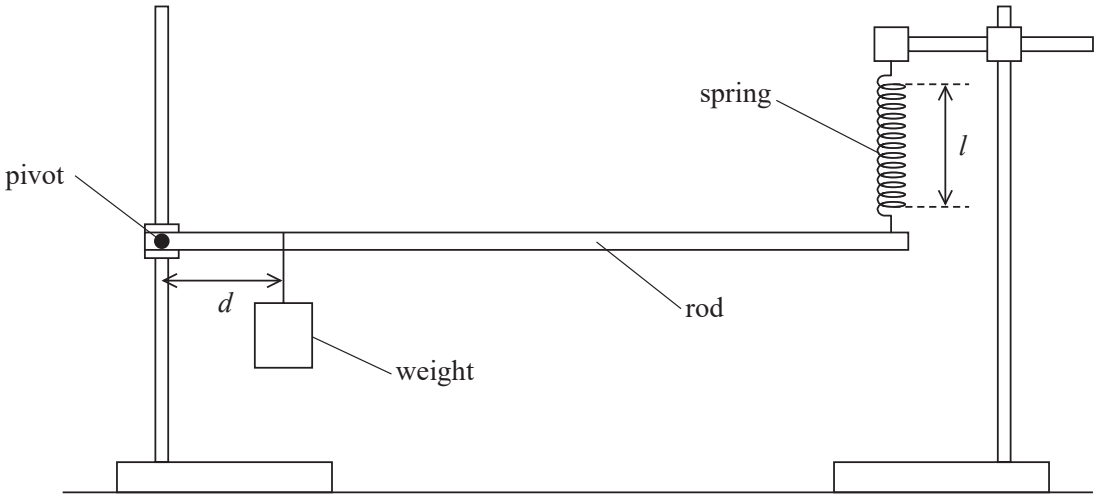
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(b) The student used the spring to investigate the forces on a uniform rod. One end of the rod was attached to a pivot and the other end was supported by the spring. The distance between the pivot and the spring stayed constant.

A weight was attached to the rod at a distance d from the pivot, as shown. The stretched length of the spring was l.



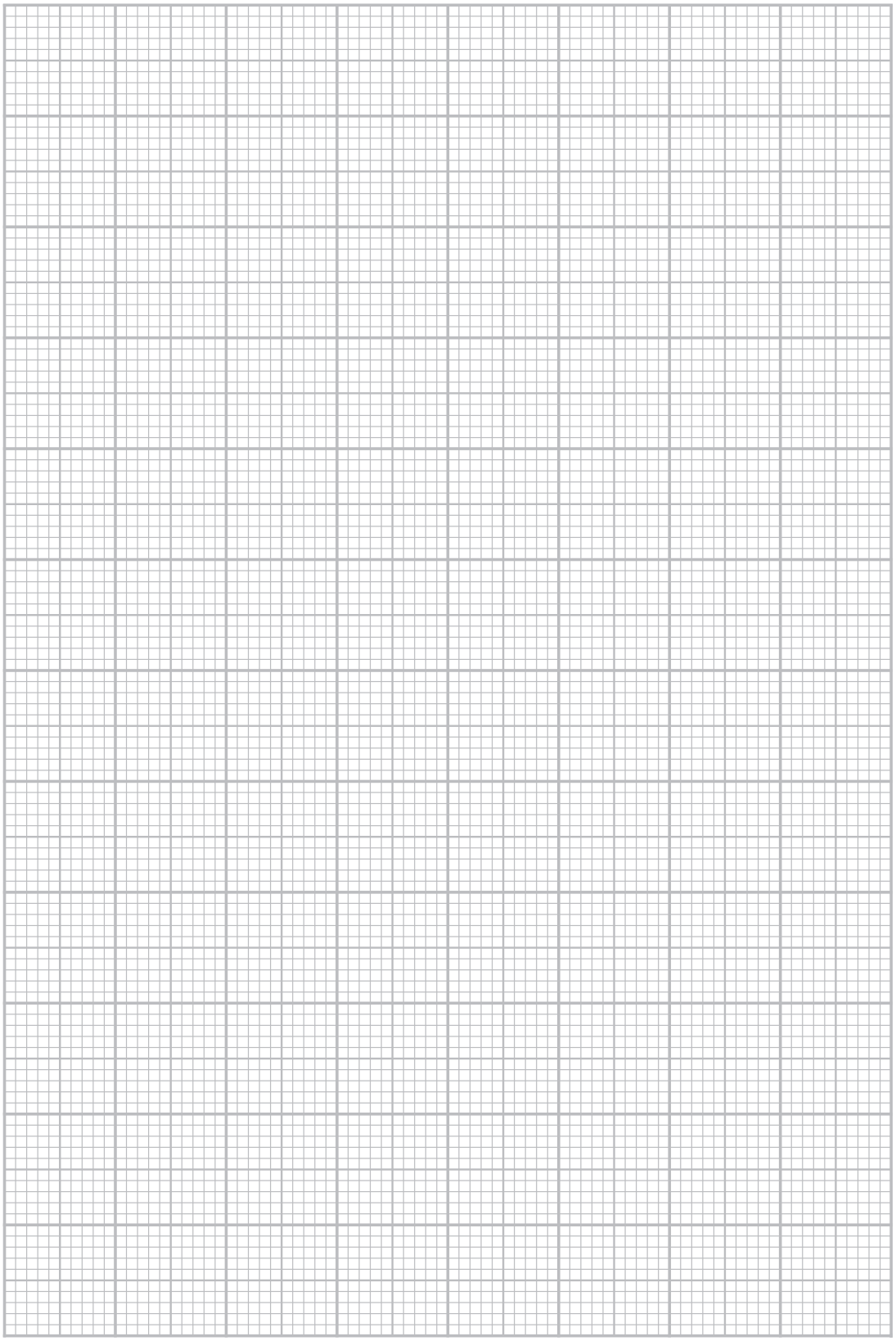
The student changed the position of the weight to vary d and measured corresponding values of l. The results are recorded below.

d / cm	l / cm	
10.0	6.6	
20.0	8.4	
30.0	10.9	
40.0	13.0	
50.0	15.3	
60.0	17.3	

(i) Plot a graph of the extension Δl of the spring on the y-axis against d on the x-axis on the grid opposite. Use the additional column of the table for your processed data.

unstretched length of spring = 3.5 cm

(5)



(ii) The student was given the following relationship

$$\Delta l = \frac{Wd}{kD} + C$$

where C is a constant
D is the distance from the pivot to the spring = 0.875 m
W is the weight on the rod = 5.00 N

Determine the spring constant k using data from the graph.

(4)

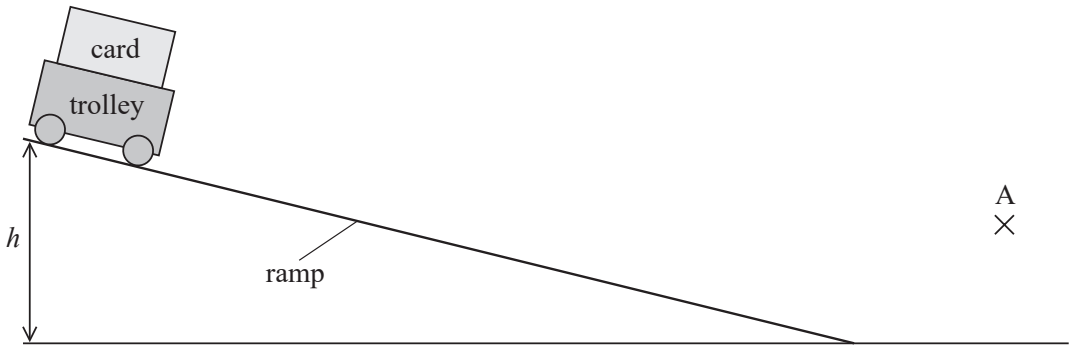
k = ...

(Total for Question 16 = 11 marks)

16 A student released a trolley from the top of a ramp of length of about 1.5 m, as shown.

The student investigated how the speed v of the trolley at the bottom of the ramp varied as the height h of the ramp was increased.

The student placed a light gate connected to a data logger at position A to measure v as the card passed through the light gate.



(a) Describe how the student could measure h accurately.

(2)

(b) The student derived the following equation for the motion of the trolley

$$h = \frac{v^2}{2g}$$

where g is the acceleration due to gravity.

(i) Explain why plotting a graph of h against v^2 will produce a straight line.

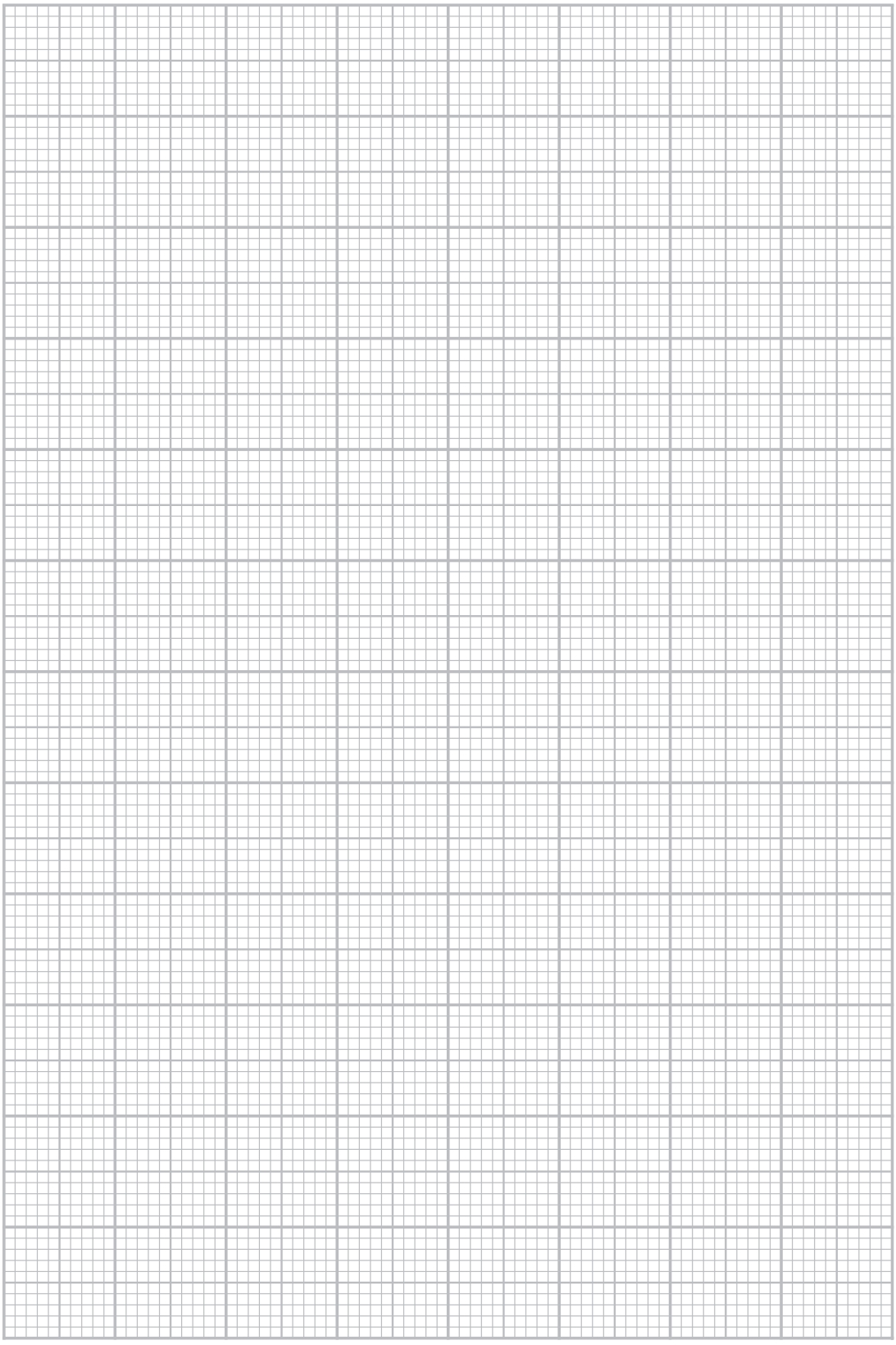
(2)

(ii) The student varied h and measured corresponding values of v. The results are recorded below.

h / cm	v / m s^{-1}	
10.8	1.38	
18.9	1.98	
28.7	2.45	
40.3	2.86	
49.8	3.22	
58.7	3.46	

Plot a graph of h on the y-axis against v^2 on the x-axis on the grid opposite. Use the additional column in the table for your processed data.

(5)



(iii) The student used her results to plot a graph and determine a value for g.

She concluded that her value was consistent with the value of g given on the data sheet at the back of this paper.

Comment on the student's conclusion.

(3)

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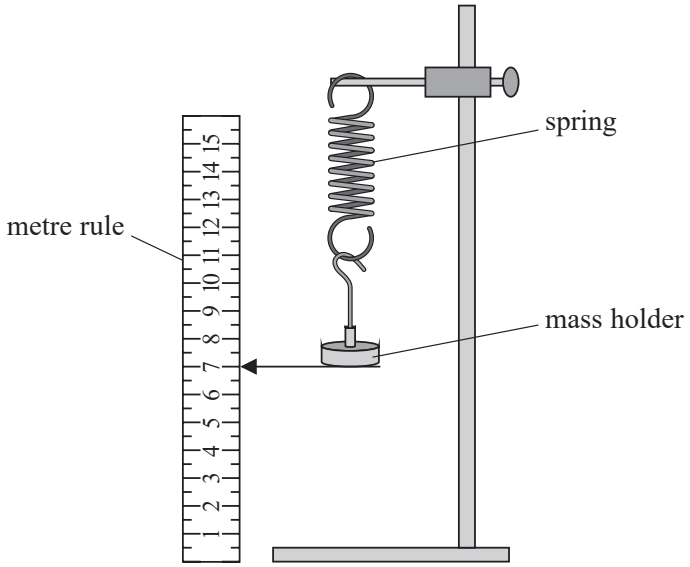
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(Total for Question 16 = 12 marks)

11 A student investigated the behaviour of a spring under tension. The spring was hung vertically with a mass holder attached.



The position of the bottom of the mass holder was recorded. The spring was stretched by adding masses to the mass holder and the new positions were recorded. The extension of the spring each time was calculated.

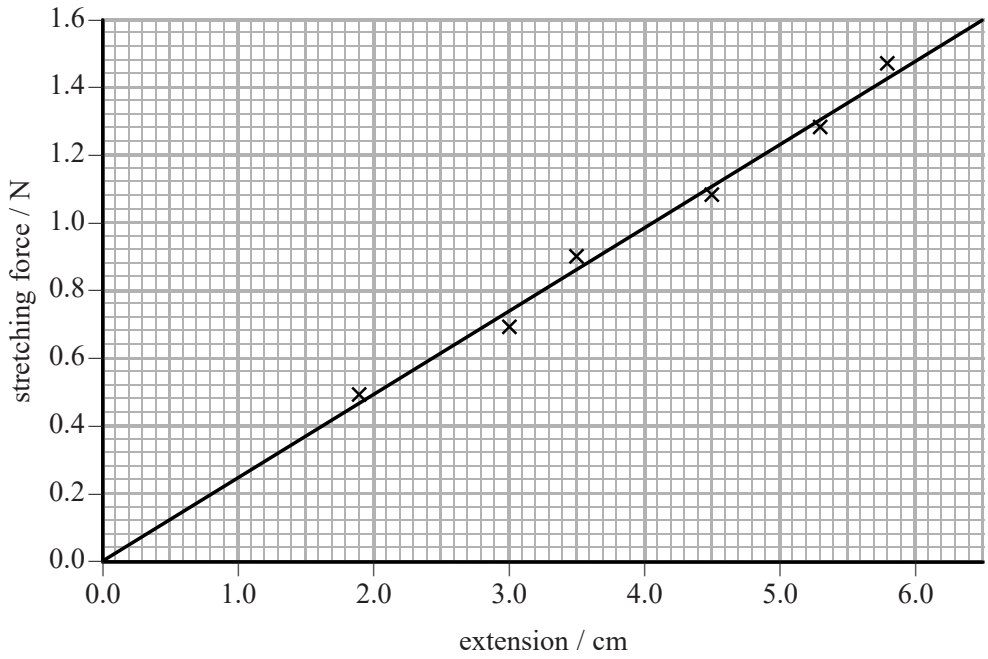
The student produced the following table.

Mass added / g	Extension / cm	Stretching force / N
50	1.9	0.49
70	3	0.69
90	3.5	0.9
110	4.5	1.08
130	5.3	1.28
150	5.8	1.47

(a) Criticise the student's table.

(2)

(b) The student used her data to plot a graph as shown.

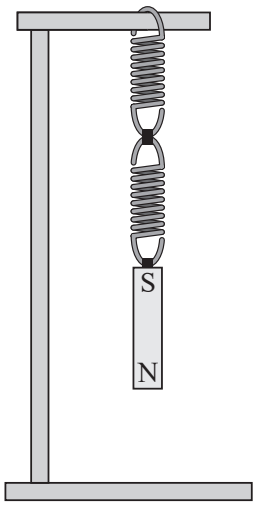


Determine a value for the force constant k of the spring.

(2)

k = ...

(c) Two identical springs are joined in series and a bar magnet is hung from one end as shown.



The bar magnet is displaced a small distance vertically from its equilibrium position and released.

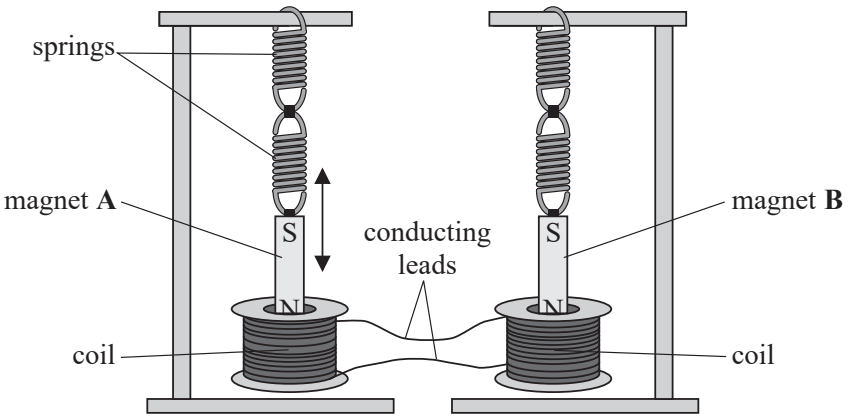
Calculate the frequency at which the system oscillates.

mass of magnet = 120 g
spring constant of each spring = 22 N m^{-1}

(4)

Frequency = ...

*(d) Identical bar magnets are suspended from identical springs, with the North pole of each magnet inside a coil of wire as shown. The two coils are connected together with conducting leads.



Magnet A is displaced so that it oscillates vertically. The North pole of magnet A moves into and out of the coil of wire with simple harmonic motion. As this motion continues, magnet B starts to oscillate. The amplitude of oscillation of magnet B increases over time.

Explain why magnet B starts to oscillate with an increasing amplitude.

(6)

(Total for Question 11 = 14 marks)

8 A student investigated the rate at which a hot liquid transfers thermal energy to the surroundings. He placed hot water in a Pyrex beaker and measured the temperature of the water using a liquid-in-glass thermometer.

He obtained the following data for the temperature θ of the water at times t. He measured t using a stopwatch.

t / s	θ / °C		
0	95		
120	87		
240	81		
360	76		
480	71		

temperature of surroundings = 23 °C

Theory suggests that a liquid transfers internal energy to the surroundings at a rate proportional to the temperature difference $\Delta\theta$ between the liquid and the surroundings.

This leads to the expression

$$\Delta\theta = \Delta\theta_0 e^{-bt}$$

where b is a constant and $\Delta\theta_0$ is the initial temperature difference.

(a) Explain why a graph of ln $\Delta\theta$ against t should be a straight line.

(2)

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.....

(b) (i) Plot a graph of ln $\Delta\theta$ against t on the grid opposite.
Use the columns provided in the table to show any processed data.

(5)

(ii) Determine the value of b.

(3)

$b =$ .....

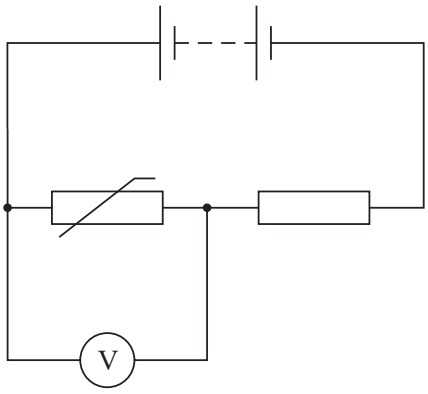
(c) The student suggested that the experiment would have been more accurate if a temperature sensor and data logger had been used to collect the data.

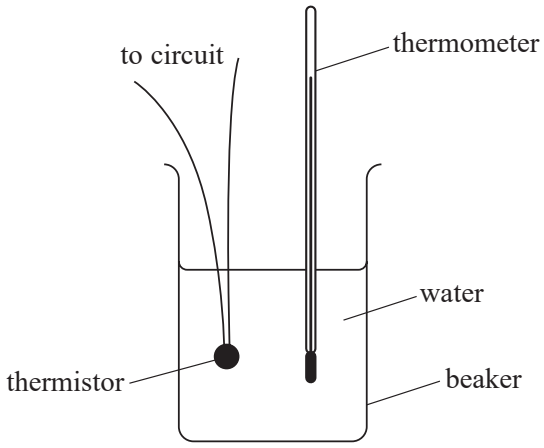
Assess the validity of the student's suggestion.

(4)

(Total for Question 8 = 14 marks)

11 A student carried out an experiment to calibrate a thermistor. She connected the thermistor in series with a resistor and a power supply as shown. Then she placed the thermistor in a beaker of hot water and used a thermometer to record the temperature θ of the water.





The student recorded θ and corresponding values of the reading V on the voltmeter as the water cooled.

(a) Explain, making reference to charge carriers, why V increased as the water cooled.

(3)

(b) Over a limited temperature range V varies with θ according to the expression

$$V = V_0 e^{-b\theta}$$

where b and V_0 are constants.

(i) Explain why a graph of $\ln V$ against θ would give a straight line.

(2)

(ii) The student's data is shown in the table below.

θ/°C	V/V	
89.0	1.9	
74.0	2.9	
53.5	4.9	
32.5	9.1	
18.5	12.6	
3.5	18.7	

Plot a graph of $\ln V$ against θ on the grid opposite. Use the column provided to show any processed data.

(5)

(iii) Determine values for b and V_0.

(4)

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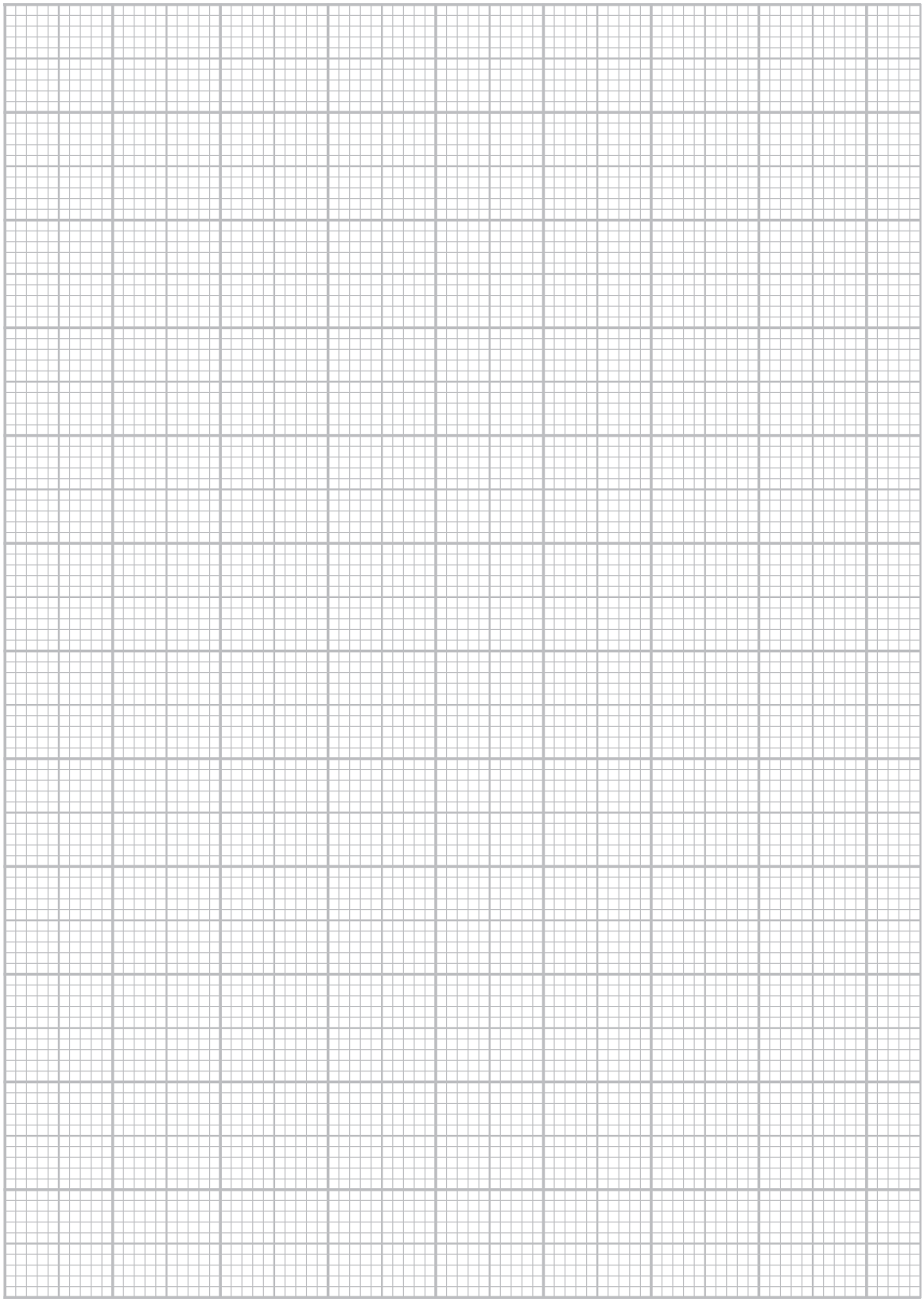
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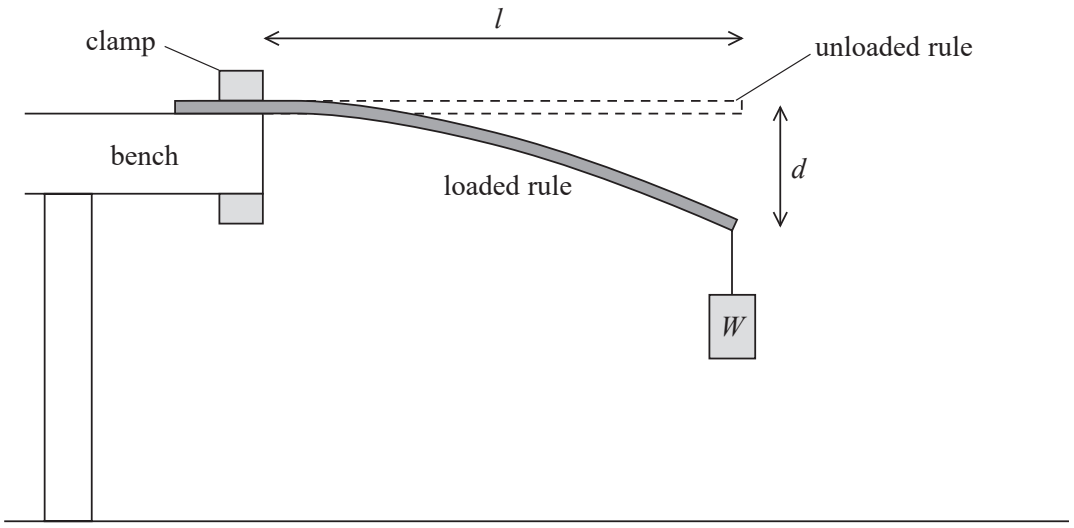
b = ...

V_0 = ...



(Total for Question 11 = 14 marks)

17 The diagram shows a wooden metre rule which is clamped horizontally to a bench. The other end of the rule is loaded with a weight W. The length l of the metre rule between the clamp and W can be varied. The loaded end of the rule is displaced through a vertical distance d as shown.



A student investigated how d varied with l.

(a) Describe how the student should use set squares and a second metre rule to determine d. You may add to the diagram.

(2)

(b) The student used the following equation for the relationship between the deflection d and the length l.

$$d = \frac{4Wl^3}{Ebt^3}$$

E is the Young modulus of the wood, b is the width of the rule and t is the thickness of the rule.

(i) The student measured t several times and calculated its mean value $\bar{t}$.

t / mm				$\bar{t}$ / mm
6.25	6.27	6.29	6.24	6.26

Calculate the percentage uncertainty in the thickness of the rule.

(2)

.....

.....

.....

.....

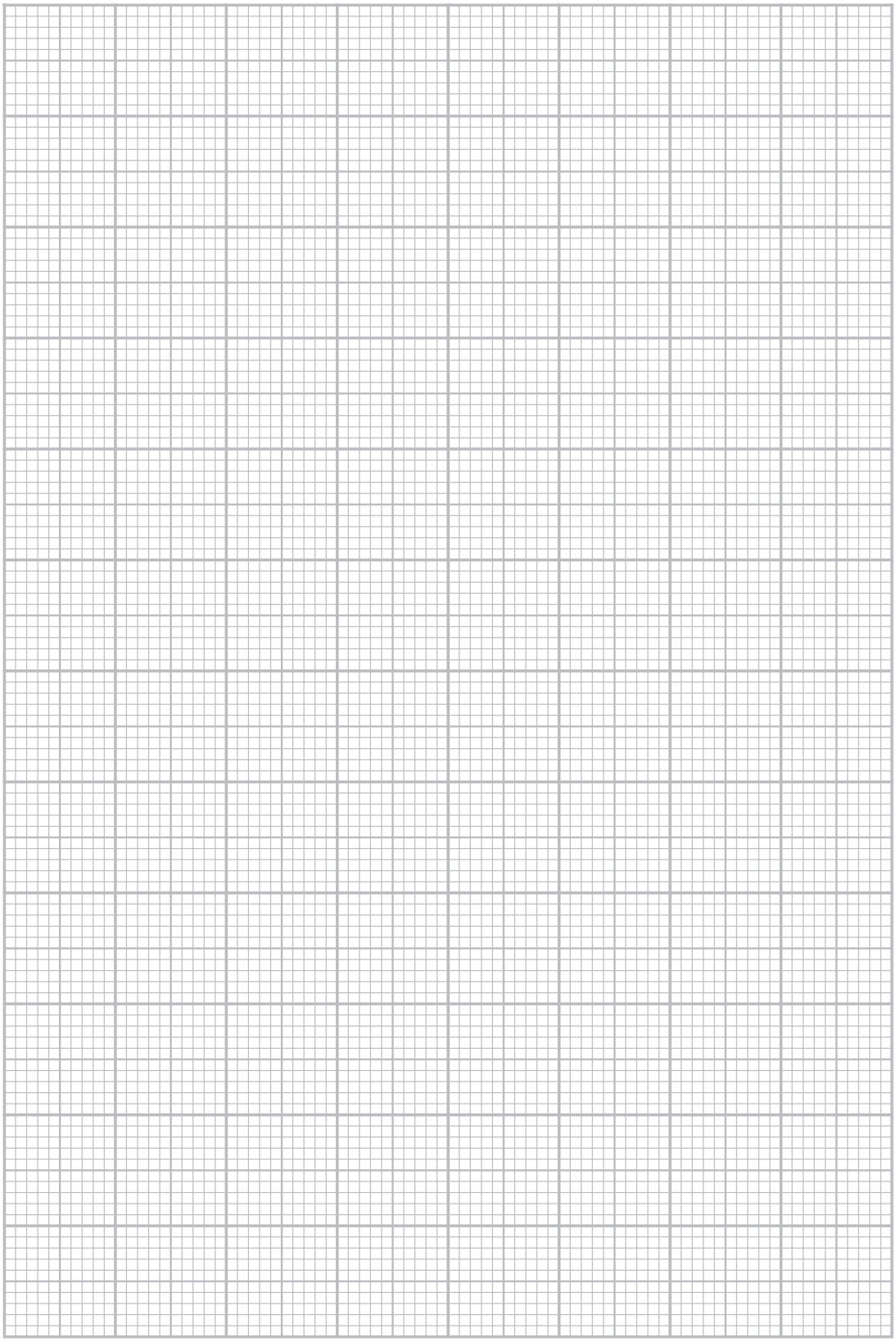
Percentage uncertainty = ...

(ii) The student's results are shown in the table.

l / m	d / mm	
0.300	6	
0.400	18	
0.500	39	
0.600	68	
0.700	107	
0.800	166	

Plot a graph of d on the y-axis against l^3 on the x-axis on the grid opposite.
Use the additional column of the table for your processed data.

(5)



(iii) The table gives the value of E for several types of wood.

Wood type	E / GPa
Pine	6.9
Douglas fir	9.7
Spruce	11.1
Birch	13.9

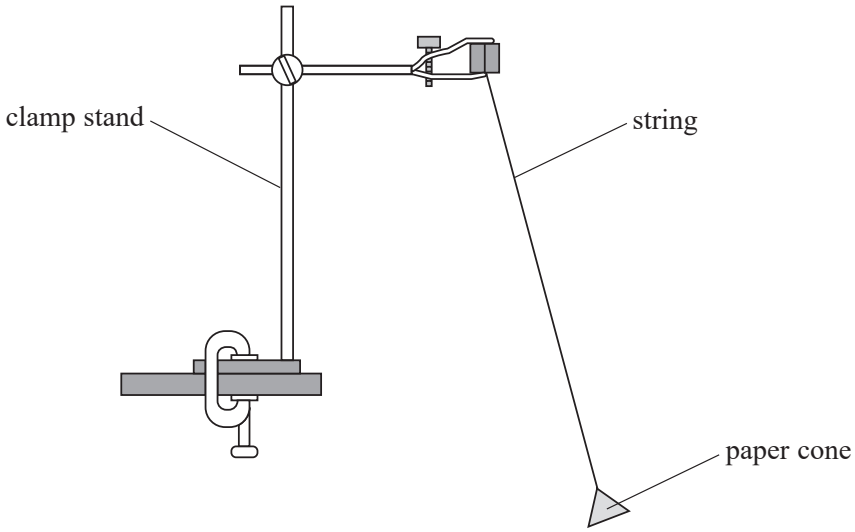
Deduce the type of wood from which the rule was made.

$W = 5.6\,\text{N}$
$b = 3.02\,\text{cm}$
$t = 6.26\,\text{mm}$

(5)

(Total for Question 17 = 14 marks)

10 A student made a simple pendulum by connecting a paper cone to a piece of string.
She attached the pendulum to a clamp as shown.



(a) (i) The student displaced the pendulum through a small angle so that it oscillated.
She determined the time period T as 2.50 s.

Calculate the length of the pendulum.

(2)

Length of pendulum = ...

(ii) Explain why the amplitude of oscillation of the pendulum did not stay constant.

(3)

(b) The student recorded how the amplitude of oscillation varied over time.

(i) It is suggested that the relationship between amplitude A and time t is

$$A = A_0 e^{-\frac{kt}{T}}$$

where A_0 is the initial amplitude of the oscillation and k is a constant.

Explain why a graph of $\ln A$ against t would give a straight line.

(2)

.....

.....

.....

(ii) The table shows the student's data.

t/s	A/cm	
2.5	17.6	
5.0	14.3	
7.5	11.6	
10.0	9.4	
12.5	7.6	

Plot a graph of $\ln A$ against t on the grid opposite. Use the additional column to show your processed data.

(5)

(iii) Determine values for A_0 and k.

(4)

.....

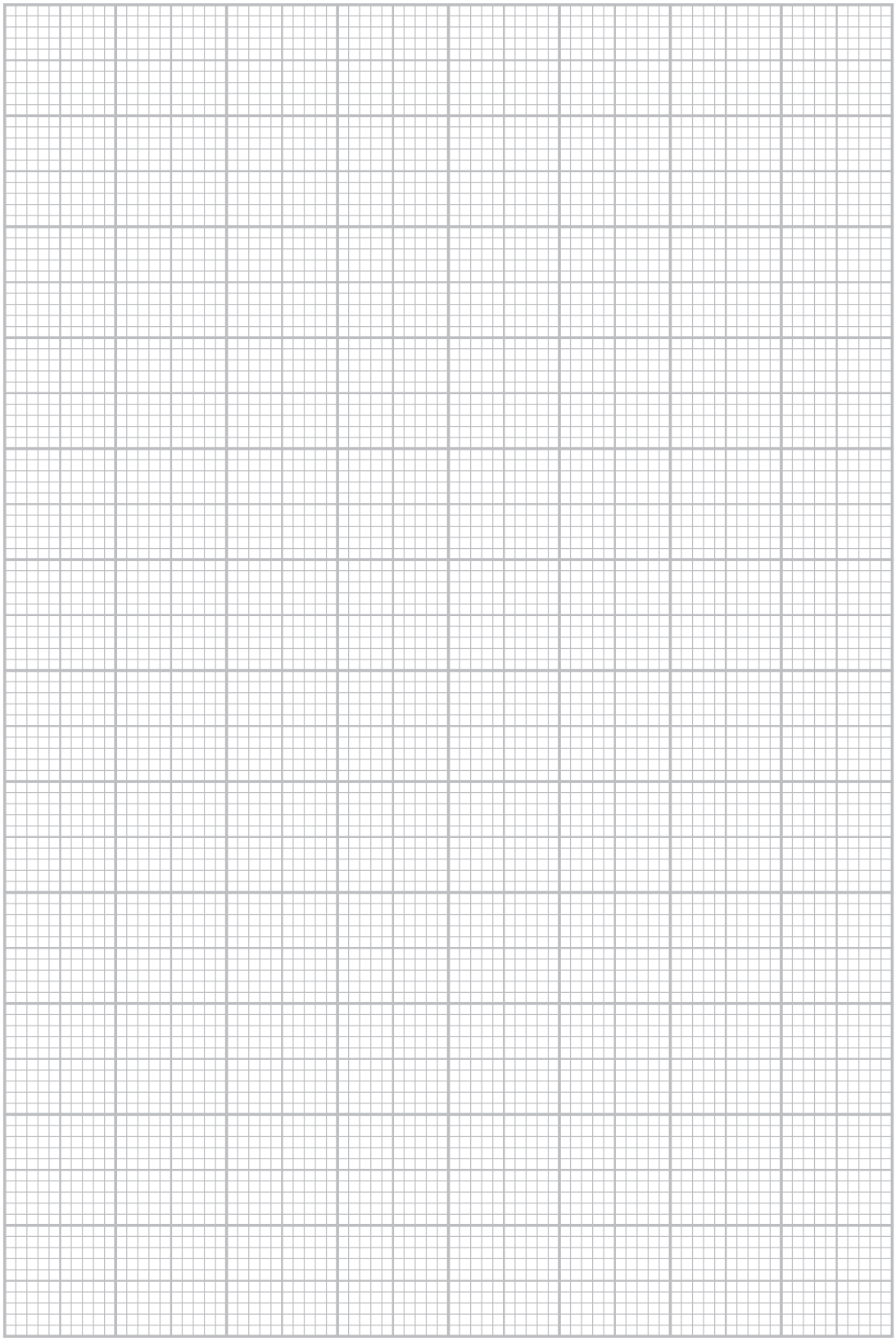
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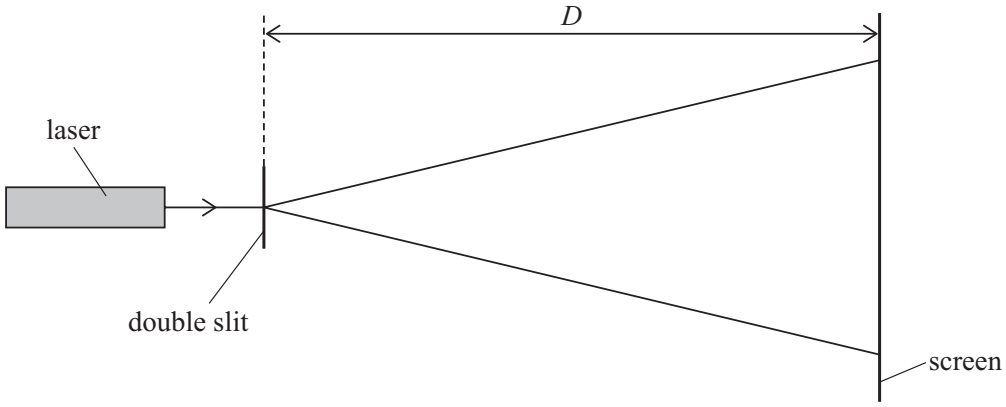
A_0 = ...

k = ...

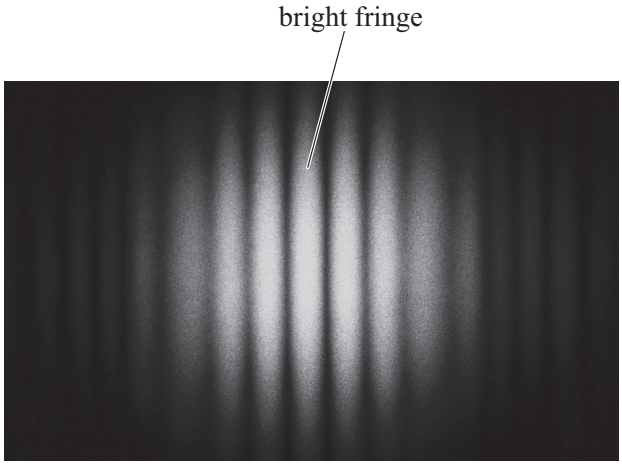


(Total for Question 10 = 16 marks)

16 A student directed light from a laser onto a double slit. The double slit consisted of two parallel narrow slits a distance s apart. The light spread out as it passed through the double slit and hit a screen a distance D away from the double slit, as shown.



The light produced a pattern of bright and dark fringes on the screen, as shown below.



(Source: © GIPhotoStock/SCIENCE PHOTO LIBRARY)

(a) The student used digital calipers to measure the separation of the fringes w by measuring between the centres of adjacent fringes.

Explain how the student could reduce the percentage uncertainty in his measurement of w.

(2)

.....

.....

.....

.....

(b) The student varied s for the double slit and recorded corresponding values of w. The results are recorded below.

s / mm	w / m	
0.10	0.0643	
0.20	0.0301	
0.30	0.0204	
0.40	0.0159	
0.50	0.0131	

(i) Plot a graph of s on the y-axis and $1/w$ on the x-axis using the grid opposite.

Use the additional column in the table for your processed data.

(5)

(ii) The following equation can be used to determine the wavelength λ of laser light for the experiment.

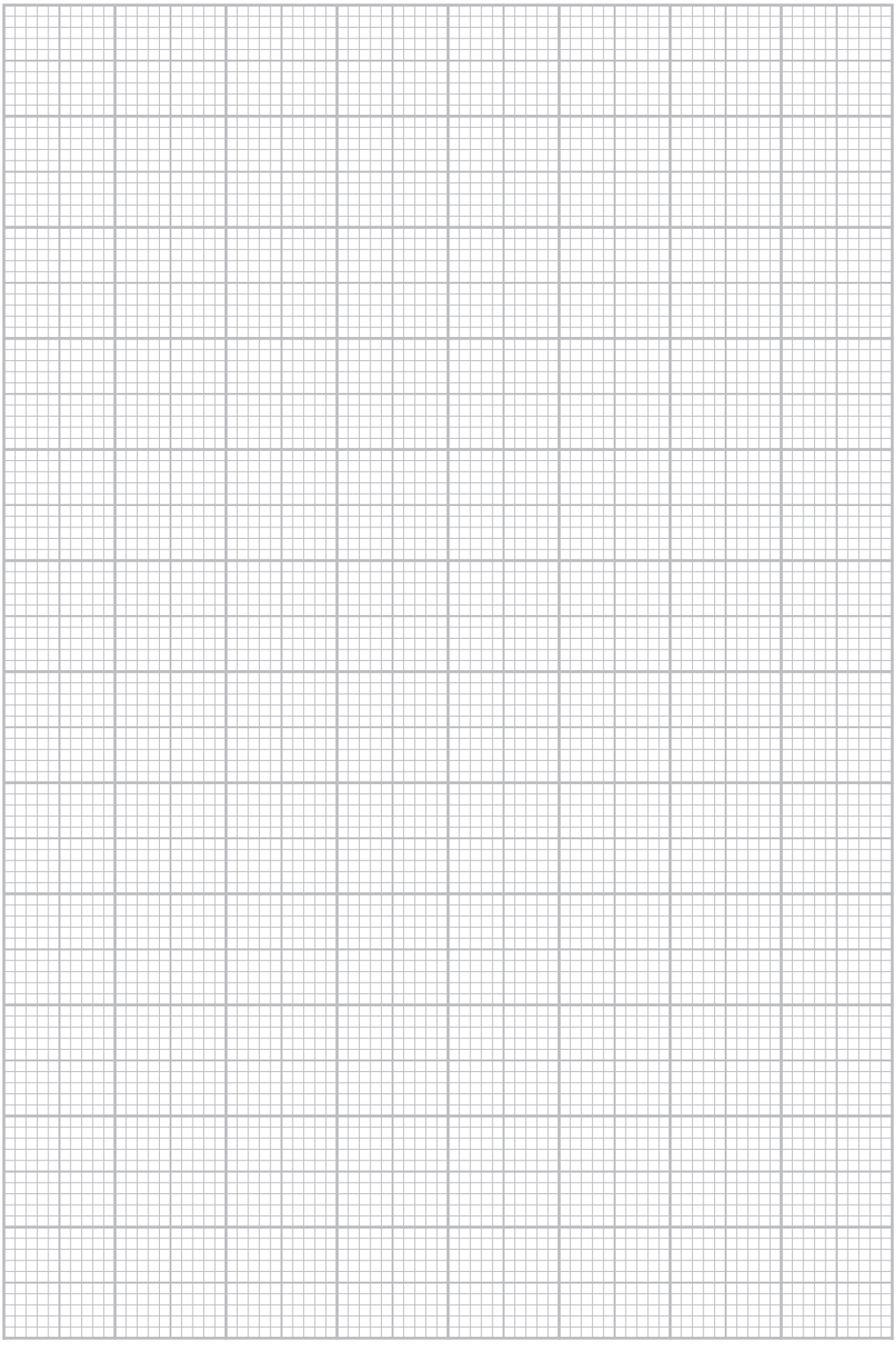
$$s = \frac{\lambda D}{w}$$

Calculate λ for the light used in this experiment.

$D = 9.00\,\text{m}$

(3)

$\lambda =$ .....



(c) Another student carried out the same experiment using a different laser labelled with a wavelength of 520 nm.

(i) She measured w several times for the same value of s. The results are recorded below.

w / mm				w_{mean} / mm
21	20	23	24	22

Calculate the percentage uncertainty in the value of w.

(2)

Percentage uncertainty in w = ...

(ii) Assess whether the student's results support the value of the wavelength of light given on the label.

$$s = \frac{\lambda D}{w}$$

$D = 9.00\,\text{m} \pm 0.01\,\text{m}$
$s = 0.20\,\text{mm} \pm 4\%$

(4)

(Total for Question 16 = 16 marks)

MARK SCHEMES

official mark schemes

Question Number	Acceptable Answer	Additional Guidance	Mark
5	**D** kg m s^{-2}		**1**

Question Number	Acceptable answers	Additional guidance	Mark
6	**The only correct answer is A** B *is not correct because these are base units of force* C *is not correct because these are not base units* D *is not correct because these are not base units*	kg m s^{-1}	**1**

Question Number	Answer	Mark
1	**D power kg m^2 s^{-3}**	**1**
	Incorrect Answers: A – Coulombs is not an SI base unit B – Incorrect, as the unit for charge in SI base units is A s C – J s^{-1} is not in SI base units	

Question Number	Acceptable answers	Additional guidance	Mark
2	A		1

Question Number	Answer	Mark
4	**A** kg s^{-2}	**1**
	Incorrect Answers: B – base units for N C – incorrect units and not base units D – correct units but not base units	

Question Number	Acceptable answers	Additional guidance	Mark
4	**The only correct answer is A** **ampere**	B,C and D are not base units	**1**

Question Number	Acceptable answer	Additional guidance	Mark
1	B	The only correct answer is **B** because m is the SI unit for length. A is not correct because C is not a base unit C is not correct because g is not a base unit D is not correct because °C is not a base unit	**1**

Question Number	Answer	Mark
6	**D $kgm^2s^{-3}A^{-1}$**	**1**
	Incorrect Answers: **A** – correct units but J and C are not base units **B** – correct units but J is not a base unit	
	C – correct units but C is not a base unit	

Question Number	Answer	Mark
1	**B**	**1**
	Incorrect Answers: **A** energy is a derived quantity **C** speed is a derived quantity **D** velocity is a derived quantity	

Question Number	Answer	Additional Guidance	Mark
1	**D is the only correct answer**	A is incorrect because coulombs is a derived unit and amperes is a base unit B is incorrect because joules is a derived unit C is incorrect because newtons is a derived unit and kilograms is a base unit	**1**

Question Number	Answer	Mark
1	**D – derived unit**	**1**
	Incorrect Answers: A – not a base quantity B – not a base unit C – not a derived quantity	

Question Number	Answers	Mark
4	**The only correct answer is C** ***A*** *is incorrect because luminosity must have the units of power* ***B*** *is incorrect because luminosity must have the units of power* ***D*** *is incorrect because luminosity must have the units of power*	**1**

Question Number	Answer	Mark
2	**C kg m^2 s^{-3} A^{-2}**	**1**
	Incorrect Answers: A – Ω is not a base unit B – V is not a base unit D – C is not a base unit	

Question Number	Answer	Mark
3	**C kg m^2 s^{-1}**	**1**
	Incorrect Answers: **A** – N is not an SI base unit and incorrect arrangement **B** – N is not an SI base unit **D** – incorrect arrangement	

Question Number	Answer	Mark
1	**B** n no unit *d* mm	1
	A – *d* incorrect C – *n* and *d* incorrect D– *n* and *d* incorrect	

Question Number	Acceptable answers	Additional guidance	Mark
1	**The only correct answer is A** B is not the correct answer, as C is not a base unit. C is not the correct answer, as J and V are not base units. D is not the correct answer, as Q is not a unit.		1

7	**The only correct answer is C** W s from the formula $P = \frac{E}{t}$ **A** *is not correct because this answer is the unit of force x time* **B** *is not correct because this answer is the unit of force* **D** *is not correct because this answer is the unit of momentum*	**1**

6	**The only correct answer is D** **A** *is not correct because* this is not a base unit **B** *is not correct because* this is not a unit for breaking stress **C** *is not correct because* this is not a base unit	**1**

Question Number	Answer	Mark
1	**The only correct answer is B,** kg m s^{-2} A is not correct because these are the base units of force C is not correct because N is not a base unit D is not correct because Pa is not a base unit	1

Question Number	Answer	Mark
3	**B - kg m s^{-2}**	1
	Incorrect Answers: A – this is the unit of momentum C – this is the unit of work done D – this is the unit of power	

8	**D 1×10^{17} J**	**1**
	A – this answer is incorrect B – this answer is incorrect C – this answer is incorrect	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
5	C The uncertainty is 0.1 s.		1

Question Number	Answer	Mark
5	**C ± 0.1 %**	**1**
	Incorrect Answers: A – the calculation has not been multiplied by 100 to give the % uncertainty i.e. $\frac{0.1}{93} = 0.001$ B – the uncertainty in mm has not been converted to cm and the calculation has not been multiplied by 100 i.e. $\frac{1}{93} = 0.01$ D – the uncertainty in mm has not been converted to cm i.e. $\frac{1}{93} \times 100 = 1$	

Question Number	Acceptable answers	Additional guidance	Mark
7	C		1

8	**C** equal to the difference between the mean and 448	**1**
	Incorrect Answers: **A** this is equal to the range **B** this is equal to the difference between the values 448 and 466 **D** this is equal to the difference between the mean and 473	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Answer	Mark
4	**A 0.4 + 0.05**	**1**
	Incorrect Answers: B – compound uncertainties by addition C – compound uncertainties by addition D – compound uncertainties by addition	

Question Number	Answer	Mark
5	**B (1.8 + 1.8) % additional of two uncertainties as A ∝ r^2**	**1**
	Incorrect Answers: **A** – incorrect, using only one value for uncertainty **C** – incorrect, addition of three uncertainties **D** – incorrect, multiplication of two uncertainties	

Question Number	Answer	Mark
4	**A** X + Y	1
	B - multiplication incorrect C – division incorrect D – subtraction incorrect	

Question Number		Additional Guidance	Mark
1(a)	• An error is the difference between the (measured) result and the true value **(1)** • An uncertainty is the interval/range in which the (true) value can be considered to lie **(1)**	Accept calculated/their for measured result/value Accept theoretical/actual value for true value	**2**
1(b)	Any **two** valid reasons that relate to • the instrument being used to make the measurement **(1)** • the way in which the measurement is made **(1)** • the quantity measured not being constant	Examples: resolution of instrument, zero error, parallax error, reaction time Vague statements that there will be random errors or there might be systematic errors not acceptable.	**2**

(Total for Question 1 = 4 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	• Accuracy is (a measure of) how close a measured/calculated value is to the true value **(1)** • Precision is (a measure of) the consistency of values obtained by repeated measurements **(1)**		**2**
1(b)	• Repeat readings can give very similar measurements so value precise **(1)** • Value is not accurate because of a systematic error **(1)**	In MP2 accept zero error or calibration or parallax error for systematic error	**2**

(Total for Question 1 = 4 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
1	An explanation that makes reference to the following points: • High precision means a small spread of values **(1)** • High accuracy means close to the true value **(1)** Any **TWO** from: • A is precise but not accurate (as there is a small spread but displaced from the centre of the target) **(1)** • B is both accurate and precise (as there is a small spread centred on the target) **(1)** • C is neither accurate nor precise (as there is a large spread displaced from the centre of the target) **(1)** • D is accurate but not precise (as there is a moderate spread centred on the target) **(1)**	Credit MP1/MP2 if the explanation of high accuracy/precision is made by reference to a relevant part of the diagram.	**4**

(Total for Question 1 = 4 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	An explanation that makes reference to the following points: • Measure the thickness of a stack of slides and divide by number of slides **(1)** • the uncertainty would be the same but the measurement would be larger (so the percentage uncertainty would be less) **(1)**		**2**
2(b)	• Precision refers to the spread of values (so the reference to precision is incorrect) **(1)** • Accuracy refers to how close the value is to the true value **(1)** • The resolution (of the balance) is 0.01 g **Or** the uncertainty (of the readings) is (half of) 0.01 g **(1)** • Repeating the measurement doesn't reduce the effect of random error **Or** Repeating the measurement and calculating a mean reduces the effect of random error **(1)**		**4**

(Total for Question 2 = 6 marks)

Question Number	Acceptable answers	Additional guidance	Mark
10(a)	• Caliper 1 gives reading to the nearest 0.01 mm **(1)** • Caliper 2 gives reading to the nearest 0.1 mm **(1)** • Technique comparison **(1)** • Statement that due to variation in diameter extra resolution of caliper 1 is irrelevant **Or** percentage error/uncertainty for caliper 1 is lower **(1)**	**MP1 and MP2,** only penalise for no unit once. Ignore references to decimal places **Examples for MP3** Caliper 2 involves judgement of which lines are aligned Caliper 1 gives direct reading Caliper 2 has parallax error	**4**
10(b)	• Use of πr^2 or $\pi d^2/4$ **(1)** • Use of $I = nAvq$ **(1)** • $v = 5.8$ to 6.0×10^{-7} m s^{-1} **(1)**	Example of calculation Cross sectional area = $\pi\frac{(12.2 \times 10^{-3}\ \text{m})^2}{4} = 1.2 \times 10^{-4}$ m^2 $1.9\ \text{A} = 1.7 \times 10^{29}\ \text{m}^{-3} \times 1.2 \times 10^{-4}\ \text{m}^2 \times v \times 1.6 \times 10^{-19}$ C $v = 5.8 \times 10^{-7}$ m s^{-1}	**3**

(Total for Question 10 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
4(a)	• Use of $T = 2\pi\sqrt{\frac{L}{g}}$ **(1)** • $L = 0.994$ m **(1)**	Example of calculation: $L = \frac{(2.00\,\text{s})^2 \times 9.81\,\text{m s}^{-2}}{4\pi^2} = 0.994\,\text{m}$	**2**
4(b)	A description that makes reference to the following points: • Record nT (where n is at least 5) **and** divide by n (to find T) **(1)** • Time oscillations from equilibrium position of bob using a (fiducial) marker **Or** repeats timings for multiple oscillations and calculate mean **(1)**		**2**
4(c)	• Using the stopwatch there would be reaction time **(1)** • The uncertainty in the measurement of the time is larger with the stopwatch than with the data logger. **(1)** • Timing multiple swings (with stopwatch) reduces %U **(1)** • Light gates are difficult to use with a pendulum bob. **(1)**	MP2 dependent on MP1	**4**

(Total for Question 4 = 8 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
3(a)	Micrometer (screw gauge)	**(1)**	Accept digital calipers	**1**
3(b)	Use of $V = \pi r^2 t$ Use of $\rho = \frac{m}{V}$ to find m Use of 0.5% to find total mass needed Number of discs = 10	**(1)** **(1)** **(1)** **(1)**	Example of calculation $V = \pi r^2 t = \pi\left(\frac{1.3\times10^{-2}\text{ m}}{2}\right)^2 \times 2 \times 10^{-3}\text{m}$ $\therefore V = 2.65\times10^{-7}\text{m}^3$ $m = \rho V = 7900\text{ kg m}^{-3}\times2.65\times10^{-7}\text{m}^3$ $\therefore m = 2.10\times10^{-3}\text{kg}$ $\frac{0.1\text{ g}}{M} = 0.5\%$ $\therefore M = \frac{0.1\text{ g}}{0.5/100} = 20\text{ g}$ $\therefore \text{number of discs} = \frac{20\text{ g}}{2.10\text{ g}} = 9.5$	**4**
3(c)	% uncertainty calculated for d or t % uncertainty calculated for cross sectional area Uncertainty in volume = (±) 4% [accept 4.0%]	**(1)** **(1)** **(1)**	Example of calculation uncertainty in $d = \frac{0.1\text{ mm}}{13\text{ mm}}\times100\% = 0.77\%$ $\therefore$ uncertainty in $A = 2 \times 0.77\%$ $= 1.5\%$ uncertainty in $t = \frac{0.05\text{ mm}}{2\text{ mm}}\times100\% = 2.5\%$ $\therefore$ uncertainty in $V = 1.5\% + 2.5\%$ $= 4.0\ \%$	**3**

(Total for Question 3 = 8 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)(i)	An explanation that makes reference to the following points: • Identify when the distance fallen between frames has become constant **(1)** • Measure the distance fallen over a number of frames **Or** measure the distance fallen between frames a number of times and calculate an average distance **(1)** • Calculate terminal velocity by dividing the distance fallen by the time taken **(1)** • Use $\frac{1}{60}$ s as time between frames. **(1)**	MP3: Allow reference to $v = \frac{s}{t}$ to calculate terminal velocity	**4**
2(a)(ii)	An explanation that makes reference to the following points: • There may be parallax error in reading the ball position **(1)** **Or** the metre rule may not be vertical • Recorded distance may be greater than actual distance, so calculated terminal velocity would be greater than true value. **(1)** **OR** **(1)** • The frame rate may be not be 60 s^{-1} • Time between frames may be less than 1/60 s, so calculated terminal velocity may be greater than true value **(1)**	Recorded distance may be less than actual distance, so terminal velocity would be less than true value Time between frames may be more than 1/60 s, so calculated terminal velocity may be less than true value	**2**

2(b)	An explanation that makes reference to the following points: • With a phone camera there won't be reaction time errors (when starting and stopping the stopwatch) **Or** with a phone camera the recording can be replayed (a number of times) **(1)** • So the uncertainty in the measured times will be reduced **Or** this may lead to a more accurate value/time/velocity **(1)**		**2**

(Total for Question 2 = 8 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
3(a)	• Use of $V = \frac{4}{3}\pi r^3$ • Use of $\rho = \frac{m}{V}$ • $\rho = 2580$ (kg m^{-3})	**(1)** **(1)** **(1)**	Example of calculation $V = \frac{4}{3}\pi\left(\frac{5.06 \times 10^{-2}\text{ m}}{2}\right)^3 = 6.78 \times 10^{-5}\text{ m}^3$ $\rho = \frac{0.175\text{ kg}}{6.78 \times 10^{-5}\text{ m}^3} = 2580\text{ kg m}^{-3}$	**3**
3(b)	• Use of half resolution to calculate % uncertainty • % uncertainty in $V = 3 \times$ % uncertainty in r • % uncertainty in $\rho =$ (% uncertainty in m + % uncertainty in V) • Use of % uncertainty to calculate upper value of density • Upper value of density 2596 (kg m^{-3}) [2616 (kg m^{-3}) if "show that" value used] • Glass is in the range and Quartz isn't, so it may not be genuine ECF from (a)	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	% uncertainty in $r = \frac{0.005\text{ cm}}{5.06\text{ cm}} \times 100\ \% = 0.10\ \%$ % uncertainty in $m = \frac{0.5\text{ g}}{175\text{ g}} \times 100\ \% = 0.29\ \%$ % uncertainty in $\rho = (3 \times 0.1\%) + 0.29\% = 0.59\%$ Range $= \pm\frac{0.6}{100} \times 2580\text{ kg m}^{-3} = \pm 15.5\text{ kg m}^{-3}$ Density range = 2565 → 2596 kg m^{-3} Allow use of half resolution in either r or m to calculate minimum V and maximum m and then calculate maximum ρ for MP1 → MP4	**6**

(Total for Question 3 = 9 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)(i)	• Calculation of mean **(1)** • Use of half range **Or** maximum difference from the mean **(1)** • % uncertainty = 1.4% **(1)**	Example of calculation $\bar{d} = \frac{(1.40+1.44+1.42+1.41)\ \text{mm}}{4} = 1.42\ \text{mm}$ $\%U = \frac{(1.44-1.40)\ \text{mm}/2}{1.42\ \text{mm}} \times 100\% = 1.41\%$	**3**
12(a)(ii)	• Use of $A = \pi r^2$ **(1)** • Use of $R = \frac{\rho l}{A}$ **(1)** • $\rho = 6.9 \times 10^{-7}$ (Ω m), so wire is made from stainless steel **(1)**	Example of calculation $A = \pi\left(\frac{1.42 \times 10^{-3}\text{m}}{2}\right)^2 = 1.58 \times 10^{-6}\ \text{m}^2$ $\rho = \frac{0.72\ \Omega \times 1.58 \times 10^{-6}\ \text{m}^2}{1.65\ \text{m}} = 6.9 \times 10^{-7}\ \Omega\ \text{m}$	**3**
12(b)	• Use of $P = \frac{V^2}{R}$ **(1)** • Use of resistance per unit length **(1)** • $l = 9.3$ m **(1)**	Example of calculation $P = \frac{(230\ \text{V})^2}{65\ \text{W}} = 813.8\ \text{m}$ $l = \frac{813.8\ \text{m}}{87.5\ \Omega\ \text{m}^{-1}} = 9.30\ \text{m}$	**3**

(Total for Question 12 = 9 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)(i)	An explanation that makes reference to the following points: • The prism and the centre of gravity are at different distances from the pivot **Or** The prism is not at the centre of gravity of the rule **(1)** • So for moments about the pivot to balance the force from the prism must be larger (than the weight of the rule) **(1)**	Allow an explanation based on use of equations. Allow "For the forces to be equal, they would have to be the same distance from the pivot to balance the moments"	**2**
3(a)(ii)	• Use of $F = mg$ **(1)** • Use of moment = Fx **(1)** • Application of principle of moments about the pivot **(1)** • $W = 0.84$ N **(1)**	Example of calculation Force at prism = F $F = (0.1802\text{ kg} - 0.0255\text{ kg}) \times 9.81\text{ N kg}^{-1} = 1.52$ N Taking moments about the pivot point $1.52\text{ N} \times (30.0 - 5.0)\text{ cm} = W \times (50.0 - 5.0)\text{ cm}$ $\therefore W = \frac{1.52\text{ N} \times 25.0\text{ cm}}{45.0\text{ cm}} = 0.84\text{ N}$	**4**
3(b)	• The distance to the pivot would increase **Or** Percentage uncertainty in distance decreases **(1)** • The force at the prism would decrease **Or** Percentage uncertainty in force/mass increases **(1)** • (As one increases and the other decreases) we cannot be sure how the percentage uncertainty would change **(1)**	Allow "reading on the balance decreases" Dependent upon MP1 and MP2	**3**

(Total for Question 3 = 9 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
6(a)	• The measurement of resistance has an uncertainty of 0.6 %	(1)	MP1 accept use of 0.05 giving 0.3 % Example of calculation: Uncertainty in $R = \frac{0.1\Omega}{18.2\Omega} \times 100\% = 0.55\%$ Uncertainty in $L = \frac{0.05\,\text{m}}{1.25\,\text{m}} \times 100\% = 4.0\%$ Uncertainty in $d = \frac{0.01\,\text{m}}{0.27\,\text{m}} \times 100\% = 3.7\%$	4
	• The measurement of the length has an uncertainty of 4 %	(1)		
	• The measurement of the diameter has an uncertainty of 4 %	(1)		
	• The % uncertainty in diameter is doubled giving the greatest amount of uncertainty into the value for the resistivity	(1)		
6(b)	• Measured diameter in multiple places / orientations **and** calculate a mean	(1)	Treat references to resolution of instrument and thickness of wire as neutral	2
	• Calculating a mean reduces the effect of random error	(1)		
6(c)	• Use of $A = \pi r^2$ with r	(1)	MP3 accept $R = 18.15\ \Omega$ MP3. Allow calculation of ρ using given values and subtraction of total % uncertainty. Example of calculation: $A = \pi r^2 = \pi \times (0.13 \times 10^{-3}\,\text{m})^2 = 5.31 \times 10^{-8}\,\text{m}^2$ $\rho = \frac{RA}{L} = \frac{18.1\Omega \times 5.31 \times 10^{-8}\,\text{m}^2}{1.30\,\text{m}} = 7.39 \times 10^{-7}\,\Omega\,\text{m}$	4
	• Use of $R = \frac{\rho L}{A}$	(1)		
	• With at least one of the following values $R = 18.1\ \Omega \quad L = 1.30\ \text{m} \quad A = \pi \times (0.13 \times 10^{-3}\,\text{m})^2$	(1)		
	• $\rho = (7.3 \rightarrow 7.4) \times 10^{-7}\,\Omega\,\text{m}$	(1)		

(Total for Question 6 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark

Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	• Use of trigonometry to determine θ **(1)** • Calculation of both angles **(1)** • Use of $d\ sin\theta = n\lambda_1$ to calculate d **(1)** • Use of $d\ sin\theta = n\lambda_2$ with d **(1)** • $\lambda_2 = 5.3 \times 10^{-7}$ m (530 nm) **(1)**	Example of calculation $\tan\theta = \frac{0.50\text{ m}}{1.45\text{ m}} \therefore \theta = 19.0^o$ $\tan\theta = \frac{0.40\text{ m}}{1.45\text{ m}} \therefore \theta = 15.4^o$ $d = \frac{650 \times 10^{-9}\text{ m}}{\sin 19.0^o} = 1.99 \times 10^{-6}\text{ m}$ $\lambda_2 = 1.99 \times 10^{-6}\text{m} \times \sin 15.4^o = 5.29 \times 10^{-7}\text{m}$	**5**
11(b)	An explanation that makes reference to the following points: • Measure the distance between the two 1st/2nd order maxima **Or** measure the distance from the 2nd order to the central maximum **Or** increase the distance from the grating to the screen • This increases the distance measured on the screen (and reduce the % uncertainty) **(1)** MP2 dependent upon MP1 **(1)**		**2**
11(c)	An explanation that makes reference to the following points: • Maxima on one side move closer to the central maximum **(1)** • Maxima on the other side move further away from the central maximum **(1)** • Intensity of maxima would be different on each side of central maximum **(1)**	Allow 1 mark for spacing of maxima on screen will change	**3**

(Total for Question 11 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
7(a)	• Measure the total thickness of a number of discs (stacked) together **(1)** • Divide by the number of discs (in the stack) to determine the average thickness of one disc **(1)** • Measure the total length of a number of discs lined up together **Or** Measure diameter of a number of discs using vernier calipers **(1)** • Divide by the number of discs to determine the average diameter of one disc **(1)**		**4**

7(b)	• Uses $V = \pi r^2 t$ **(1)** • Use of $\rho = \frac{m}{V}$ **(1)** • $\rho = 1.1 \times 10^4$ kg m^{-3} **(1)** • Uses % uncertainty in mass **or** diameter **or** thickness **(1)** • Uses 2 × % U in diameter **(1)** • % U in density = 10 % **(1)**		<u>Example of calculation</u> $V = \pi\left(\frac{5.2 \times 10^{-2}\text{ m}}{2}\right)^2 \times 1.9 \times 10^{-3}\text{ m} = 4.04 \times 10^{-6}\text{ m}^3$ $\rho = \frac{42.5 \times 10^{-3}\text{ kg}}{4.04 \times 10^{-6}\text{ m}^3} = 1.05 \times 10^4\text{ kg m}^{-3}$ For mass % U $= \frac{0.5\text{ g}}{42.5\text{ g}} \times 100\% = 1.2\ \%$ For diameter % U $= \frac{0.1\text{ cm}}{5.2\text{ cm}} \times 100\% = 1.9\ \%$ For thickness % U $= \frac{0.1\text{ mm}}{1.9\text{ mm}} \times 100\% = 5.3\ \%$ % U in density $= 1.2\ \% + (2 \times 1.9\ \%) + 5.3\ \% = 10.3\ \%$ <u>Alternative MP4 and MP5</u> • Uses absolute uncertainties to calculate upper or lower limit • Uses half range •	**6**

(Total for Question 7 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
12(a)(i)	An explanation that makes reference to the following points: • t_1 is not significantly different from the other times **Or** t_1 is only 0.6% different from t_{mean} **Or** there is not enough data to show that t_1 is anomalous **(1)** • So the student who says that all the data should be used is correct **(1)**	MP2 dependent upon MP1	**2**
12(a)(ii)	• Mean t calculated **(1)** • Uses half range **Or** Uses furthest from mean **(1)** • % U = 0.4 % given to 1 or 2 sig figs only **(1)** 0.5% using furthest from mean	Example of calculation $t_{mean} = \frac{7.85\text{ s} + 7.81\text{ s} + 7.79\text{ s} + 7.80\text{ s}}{4} = 7.81\text{ s}$ Half range $= \frac{7.85\text{ s} - 7.79\text{ s}}{2} = 0.03\text{ s}$ $\%\text{ U} = \frac{0.03\text{ s}}{7.81\text{ s}} \times 100\% = 0.38\ \%$	**3**
12(a)(iii)	• Height of cylinder **Or** Length of cylinder **(1)**		**1**

12(b)(i)	• Use of $v^2 = u^2 + 2as$ **(1)** • $v = 3.8\ \text{m s}^{-1}$ **(1)**	Example of calculation $v^2 = u^2 + 2as$ $\therefore v = \sqrt{2 \times 9.81\ \text{m s}^{-2} \times 0.75\ \text{m}} = 3.84\ \text{m s}^{-1}$	**2**
12(b)(ii)	An explanation that makes reference to the following points: • The cylinder is travelling (very) quickly (when it reaches the light gate) **(1)** • Therefore the time taken for the cylinder to pass through the light gate is (very) short **(1)** • Using the light gate and a data logger there is minimal effect from reaction time **Or** Difficult/impossible to press stopwatch button again after such a short time **(1)**		**3**

(Total for Question 12 = 11 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
5(a)(i)	• (±) 0.005 cm	**(1)**		**1**
5(a)(ii)	• Use of 2 × uncertainty • 0.07 % [1 or 2 sf] ECF answer from (a)(i)	**(1)** **(1)**	Example of calculation $\%\ \text{uncertainty in h} = \frac{2 \times 0.005\ \text{cm}}{(27.10\ -\ 12.00\ \text{cm})} \times 100\ \%$ $\%\ \text{uncertainty in h} = 0.066\ \%$	**2**
5(a)(iii)	**MAX 2** • No units given for 1/*r* in table • 1/*r* recorded to more significant figures than *r* • *h* recorded to an inconsistent number of decimal places • raw data for *h* not shown	 **(1)** **(1)** **(1)** **(1)**		**2**
5(b)(i)	• Line of best fit drawn • Value of 1/*r* calculated • *h* = 13.8 cm	**(1)** **(1)** **(1)**	Example of calulation $\frac{1}{r} = \frac{1}{0.11\ \text{mm}} = 9.1\ \text{mm}^{-1}$	**3**
5(b)(ii)	• There are only 4 points, which isn't enough to form a firm conclusion • The range of the points is insufficient to form a firm conclusion (no data between 0.0 and 6.0 on *x*-axis) **Either** • $h = \frac{k}{r}$ suggests a straight line through the origin • the points plotted do lie in a straight line **Or** • $h = \frac{k}{r}$ suggests hr is a constant • This is approximately true (k ≈ 1.5)	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	Credit there may be systematic error in *h* causing the points to be displaced	**4**

(Total for Question 5 = 12 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)(i)	• Use of $V = \pi r^2 t$ **(1)** • Use of half resolution to calculate % uncertainty in d **(1)** • % uncertainty in area = 2 × (% uncertainty in d) **(1)** • Calculation of % uncertainty in t **(1)** • % uncertainty in t added to % uncertainty in area **(1)** • $V = 5.94 \times 10^{-7}\text{m}^3$ **(1)** • $\%\ U = 0.4\ \%$ **(1)**	Allow MP4 for use of full resolution if MP2 was withheld for not using half resolution Example of calculation $V = \pi\left(\frac{22.16 \times 10^{-3}\text{m}}{2}\right)^2 \times 1.54 \times 10^{-3}\text{m}$ $\therefore V = 5.94 \times 10^{-7}\text{m}^3$ $\%\ U = \left(2 \times \frac{0.005\ \text{mm}}{22.16\ \text{mm}} + \frac{0.005\ \text{mm}}{1.54\ \text{mm}}\right) \times 100\%$ $\%\ U = 0.36\ \%$	**7**

2(a)(ii)	**EITHER** • Use of $\rho = \frac{m}{V}$ (allow use of V from (a)(i)) **(1)** • Calculation of % U in ρ **(1)** • Max density = 1.9×10^4 kg m^{-3} (ecf from (a)(i)) • 1.9×10^4 kg m^{-3} < 1.93×10^4 kg m^{-3} so coin not pure gold **(1)** **Or** comparison of calculated value of max density with density of gold and consistent conclusion **(1)** **OR** • Use of $\rho = \frac{m}{V}$ to calculate mass of pure gold coin **(1)** • Mass of pure gold coin = 11.5 g (ecf from (a)(i)) **(1)** • Use of half resolution to calculate max mass of coin being tested **(1)** • 11.25 g < 11.5 g, so coin is not pure gold **Or** comparison of maximum value of mass of coin with mass pure gold coin and consistent conclusion. **(1)** **OR** • Use of $\rho = \frac{m}{V}$ to calculate volume of a pure gold coin with mass 11.2g **(1)** • Use of half resolution to calculate % U in mass (0.05/11.2 × 100% = 0.44 %), and hence calculated volume **(1)** • Find the *smallest* volume possible within uncertainty from part (i) **(1)** • 5.83 x 10^{-7} m^3 < 5.91 x 10^{-7} m^3 , so coin not pure gold **Or** comparison of minimum value of volume of coin from part i with maximum volume of pure gold coin and consistent conclusion. **(1)**	For MP2, allow use of resolution if use of half resolution has already been penalised in (a)(i) Allow a conclusion that states the values are similar so it might be gold MP4, allow "density of pure gold" for 1.93×10^4 kg m^{-3} For MP3, allow use of resolution if use of half resolution has already been penalised in (a)(i) MP4: allow "density of pure gold" for 1.93×10^4 kg m^{-3} <u>Example of calculation</u> $\rho = \frac{m}{V} = \frac{11.2 \times 10^{-3}\text{kg}}{5.94 \times 10^{-7}\text{m}^3} = 1.89 \times 10^4$ kg m^{-3} $\%\ U = \frac{0.05\ g}{11.2\ g} \times 100\% + 0.36\% = 0.81\ \%$ $\therefore$ range $= \pm 1.89 \times 10^4$ kg $\times 0.008 = \pm 152$ kg m^{-3} $\therefore$ max density $= 18900 + 150 = 19050$ kg m^{-3}	**4**

2(b)	**MAX 4** • Measure thickness of a stack of coins **Or** measure the mass of a stack of coins • (Uncertainty remains the same, so) % U is reduced [MP2 dependent on MP1 • Determine diameter/mass/thickness by repeating measurement and calculating a mean • This reduces the effect of random errors • Check and correct for zero error on calipers or balance • This reduced the effect of systematic error	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	MP1 accept measuring a number of coins side by side MP1 accept using a balance with a higher resolution MP2 as this would reduce the uncertainty MP4 dependent on MP3 MP6 dependent on MP5	**4**

(Total for Question 2 = 15 marks)

Question Number	Acceptable Answer	Additional Guidance Whole question to be clipped together to allow full ECF	Mark
10(a)(i)	• Calculation of mean value **(1)** • Use of $l = \pi w$ **(1)** • l= 48.1 mm (3 sf) **(1)**	Example of calculation: $w = \frac{(15.3+15.2+15.4+15.3)}{4} = 15.3$ mm $l = \pi \times 15.3$ mm $= 48.1$ mm	**3**
10(a)(ii)	• Calculation of half range **Or** greatest deviation from mean **(1)** • % uncertainty = 0.7 % **(1)** **Allow ECF from (a)(i)**	Example of calculation: Half range value $= \frac{15.4 \text{ mm} - 15.2 \text{ mm}}{2} = 0.1$ mm $\therefore$ % uncertainty $= \frac{0.1 \text{ mm}}{15.3 \text{ mm}} \times 100\ \% = 0.65\ \%$	**2**
10(a)(iii)	• Use of $L = Nl$ with N = 16 **or** 18 **(1)** • L = 866 mm [0.866 m] **(1)** **Allow ECF from (a)(i)**	Example of calculation: $L = 18 \times 48.1$ mm $= 866$ mm	**2**
10(b)(i)	• Micrometer (screw gauge) **Or** digital calipers **(1)** • Because the measured value indicates a resolution of 0.01 mm **(1)**		**2**
10(b)(ii)	• % uncertainty = 0.2 % **(1)**	Example of calculation: % uncertainty $= \frac{0.005 \text{ mm}}{2.52 \text{ mm}} \times 100\ \% = 0.20\ \%$	**1**
10(b)(iii)	• % uncertainty = 1.6 % **(1)**	Example of calculation: % uncertainty $= \frac{0.5 \text{ g}}{32.0 \text{ g}} \times 100\ \% = 1.56\ \%$	**1**
10(b)(iv)	• % uncertainty = 2.7 % [1 or 2 sf] **(1)** **Allow ECF from (a)(ii), (bii) and (b)(iii)**	Example of calculation: % uncertainty = 0.7 % + 1.6 % + (2 × 0.2 %) = 2.7 %	**1**

10(b)(v)	• Use of V = $L \times \frac{\pi d^2}{4}$ **(1)** • Use of $\rho = \frac{m}{V}$ **(1)** • Uncertainty in density = 200 kg m^{-3} **(1)** • So maximum density is 7600 kg m^{-3} which is lower than the standard value **Or** comment consistent with their calculated value **(1)** **Allow ECF from (a)(iii) and (b)(iv)**	Example of calculation: V = 0.866 $m \times \frac{\pi(2.52\times10^{-3})^2}{4}$ = 4.32× 10^{-6} m^3 $\rho = \frac{3.20\times10^{-2}\text{ kg}}{4.32\times10^{-6}\text{m}^3}$ = 7400 kg m^{-3} Uncertainty in ρ = ±(7400 kg m^{-3} × $\frac{2.7}{100}$) = 200 kg m^{-3}	**4**

(Total for Question 10 = 16 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	**MAX 3** • The rule has a resolution of 1 mm **(1)** • The rule is not suitable to measure *t*, as the % uncertainty would be too large **(1)** • She should use vernier/digital calipers instead **(1)** • Vernier calipers have a resolution of 0.1 mm **(1)** **Or** Digital calipers have a resolution of 0.01 mm	MP3L Accept micrometer for MP3 Then, MP4; micrometer has resolution of 0.01 mm	**3**
11(b)	• Stack the washers together **(1)** • This increases the distance being measured **(1)** • So the % uncertainty is reduced **(1)**	MP1: Accept measure *t* in multiple places on washer and calculate a mean	**3**

11(c)(i)	• Uncertainty added for sums and difference **(1)** • % uncertainty calculated for sum and difference **(1)** • % uncertainties added for product **(1)** • % uncertainty in A = 2.6 (%) **(1)**	Example of calculation % uncertainty in $(d_1 + d_2) = \frac{2\times0.02\text{ cm}}{(4.52+2.53)\text{ cm}} \times 100\% = 0.57\ \%$ % uncertainty in $(d_1 - d_2) = \frac{2\times0.02\text{ cm}}{(4.52-2.53)\text{ cm}} \times 100\% = 2.0\ \%$ % uncertainty in $(d_1 + d_2)\ (d_1 - d_2)$ = 0.6% + 2.0% = 2.6 %	**4**
11(c)(ii)	• Mean t = 4.1 (mm) **(1)** • Use of half range value to calculate % U in t **(1)** • Calculates volume from area and thickness **(1)** • Use of $\rho = \frac{m}{V}$ **(1)** • Calculates % U in density (ecf from (c)(i)) **(1)** • Range of density is from 6.6 g cm^{-3} to 7.6 g cm^{-3}, so washer is made of iron. **(1)**	Example of calculation $\bar{t} = \frac{(4.3 + 4.2 + 4.1 + 3.9 + 4.0)\text{ mm}}{5} = 4.1\text{ mm}$ % U in $t = \frac{(4.3 - 3.9)\text{ mm}/2}{4.1\text{ mm}} \times 100\ \% = 4.9\ \%$ $V = \frac{\pi}{4}(4.52 + 2.53)\text{cm} \times (4.52 - 2.53)\text{cm} \times 0.41\text{cm} = 4.52\text{ cm}^3$ $\rho = \frac{32.0\text{ g}}{4.52\text{ cm}^3} = 7.08\text{ g cm}^{-3}$ % U in ρ = 2.6 % + 4.9 % = 7.5 % Maximum value of ρ = 1.075 ×7.08 g cm^{-3} = 7.61 g cm^{-3} Minimum value of ρ = 0.925 ×7.08 g cm^{-3} = 6.55 g cm^{-3} Only iron has a density within range, so the washers are made from iron	**6**

(Total for Question 11 = 16 marks)

Question Number	Answer	Mark
1	**B** micrometer screw gauge (has a resolution of 0.01mm, less than the thickness of a piece of paper)	**1**
	Incorrect Answers: **A** - measuring tape (has a resolution of 1mm, greater than the thickness of a sheet of paper) **C** - ruler (has a resolution of 1mm, greater than the thickness of a sheet of paper) **D** - vernier calipers (has a resolution of 0.1mm, approximately the same as the thickness of a sheet of paper)	

Question Number	Answer	Mark
2	**B** metre rule and micrometer	1
	A - stopwatch incorrect C - stopwatch incorrect D- stopwatch incorrect	

Question Number	Acceptable Answers		Additional Guidance	Mark
10	• Calculate force = mg	(1)		
	• calculate the cross-sectional area $A = \pi\frac{d^2}{4}$	(1)	Accept $A = \pi r^2$ **and** $r = \frac{d}{2}$	
	• x- and y- variables to produce a suitable straight-line graph	(1)	Accept stress and strain only if definition of each is given	
	• correct use of the gradient from their graph to determine E	(1)		
				4
	Total for question 10			**4**

Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	• Use a micrometer to measure y and/or z **(1)** • Use Vernier/digital calipers to measure x and/or z **(1)** • Mass of slide(s) measured using (top pan) balance/scales **(1)** • Repeat and determine mean for at least one measurement **(1)**	**(Part (a) and (b) to be marked holistically** **MP1** accept digital calipers for a single slide Accept Vernier calipers if it is clear that the thickness of a number of slides is being measured. To award both MP1 & 2, *x, y* & *z* must all be referred to. MP4 can be awarded for a reference to averaging any of the measurements.	**4**
2(b)	Check zero error on micrometer/callipers/balance **Or** measure *x/y/z* of slide in different places **Or** measure thickness/mass of multiple slides **(1)**	Accept 'tare' for zero error check on balance	**1**

(Total for Question 2 = 5 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	• Systematic (error) **(1)**		**1**
1(b)	• (Take readings at) different places/positions **(1)** • (Take readings at) different orientations/angles **(1)** • Calculate a mean/average value **(1)**		**3**
1(c)	• There will be variations in positioning the (jaws of the) micrometer. **Or** There will be variations in the length of the tube (at different points around the circumference of the tube) **(1)**	(Accept any reasonable practical physics alternative)	**1**

(Total for Question 1 = 5 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
4	• $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, re-arranged to make $\frac{1}{v}$ the subject **(1)** • Comparison with $y = mx + c$ **(1)** • So intercept equals $1/f$ **(1)** • Use the y intercept to calculate a value for f **(1)** • Comment on the agreement with the initial determination including an appropriate justification **(1)** **OR** • Since $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, when $\frac{1}{u} = 0$, $f = v$ **(1)** • When $\frac{1}{v} = 0$, $f = v$ **(1)** • Use the y intercept to calculate a value for f **(1)** • Use the x intercept to calculate a value for f **(1)** • Comment on the agreement with the initial determination including an appropriate justification **(1)** **OR** • Read a pair of corresponding values from the graph **(1)** • Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ to calculate a value for f **(1)** • Read a second pair of corresponding values from the graph **(1)** • Use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ to calculate a second value for f **(1)** • Comment on the agreement with the initial determination including an appropriate justification **(1)**	$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ $y = mx + c$	**5**

(Total for Question 4 = 5 marks)

Question Number	Acceptable answers	Additional guidance	Mark
10	• calculation of gradient of the graph **(1)** • Use of $s = ½\ at^2$ to obtain value for g **(1)** • Total uncertainty = 7 % **(1)** • Calculation of % difference **Or** Range of calculated g **(1)** • Judgment on accuracy of experiment with reason **(1)**	MP2: use of $\frac{2}{\text{gradient}}$ MP3: percentage uncertainty = 3 % + 3 % + 1 % MP5: e.g. comparison of total uncertainty with % difference **Or** comparison of calculated range with 9.81 m s^{-2} <u>Example of calculation</u> Gradient = $\frac{0.385\ s^2 - 0.06\ s^2}{1.8\ m - 0.4m} = 0.232\ s^2\ m^{-1}$ $g = \frac{2}{0.232\ s^2\ m^{-1}} = 8.67\ m\ s^{-2}$ Percentage difference $= \left(\frac{9.81\ m\ s^{-2} - 8.67\ m\ s^{-2}}{9.81\ m\ s^{-2}}\right) \times 100 = 12\ \%$	**5**

(Total for Question 10 = 5 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	• Data not recorded to the same s.f./d.p. **(1)** • Position of mass holder not recorded **(1)**		**2**
1(b)	• Calculate mean value of position of mass (holder) by taking loading and unloading positions of mass (holder) **Or** calculate mean value by taking repeat readings/measurements (for each mass) **(1)** • Use a pointer on mass (holder to ensure that position of mass holder is read correctly) **Or** take readings at eye level (to ensure that position of mass holder is read correctly) **Or** use a set square to take readings from metre rule (to ensure that position of mass holder is read correctly) **Or** bring metre rule as close as possible to mass (holder) **(1)** • Check that metre rule is vertical **Or** fix metre rule in position **(1)**		**3**

(Total for Question 1 = 5 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16	**Either** • As x increases, the (clockwise) moment of the load about P increases **(1)** • (For equilibrium) the clockwise moment and the anticlockwise moment about P must be equal **(1)** • So F_Q must increase (to increase the anticlockwise moment) MP3 dependent on MP2. **(1)** • (For equilibrium) the resultant vertical force must be zero **Or** As x increases, the (anticlockwise) moment of the load about Q decreases **(1)** • As F_Q increases F_P must decrease **(1)**		

	OR • As x increases, the (anticlockwise) moment of the load about Q decreases **(1)** • (For equilibrium) the clockwise moment and the anticlockwise moment about Q must be equal **(1)** • So F_P must decrease (to decrease the clockwise moment) MP3 dependent on MP2 **(1)** • (For equilibrium) the resultant vertical force must be zero **Or** As x increases, the (clockwise) moment of the load about P increases **(1)** • As F_P decreases F_Q must increase **(1)**			**5**

(Total for Question 16 = 5 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
2(a)	• The data has to be collected over a long period of time	**(1)**		**1**
2(b)(i)	An explanation that makes reference to the following: • The (terminal) p.d. (of the cell) decreases. • $I = \frac{V}{R}$, so the current decreases as the (external) resistance in the circuit stays constant	**(1)** **(1)**	In MP1 do not accept voltage for p.d. MP2: Accept $I \propto V$ because (external) resistance in the circuit is constant, so the current decreases	**2**
2(b)(ii)	• Use of $I = \frac{V}{R}$ with R = 220 Ω or (220 + r) • (Sum of e.m.f. = sum of p.d. leading to) use of $r = \frac{(\varepsilon - V)}{I}$ with I from MP1 • r = 30 Ω (allow answers in range 28 Ω – 32 Ω)	**(1)** **(1)** **(1)**	Answer in range with no working shown scores MP3 only Example of calculation $I = \frac{3.52\ \text{V}}{220\ \Omega} = 1.60 \times 10^{-2}\ \text{A}$ $r = \frac{\varepsilon - V}{I} = \frac{(4.0\text{-}3.52)\ \text{V}}{1.60 \times 10^{-2}\ \text{A}} = 30.0\ \Omega$	**3**

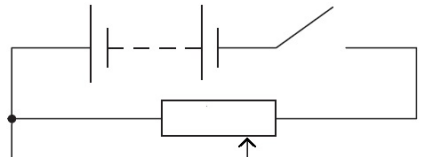
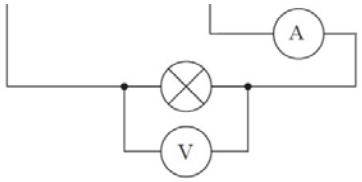
(Total for Question 2 = 6 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	• Use of $F = BIl\sin\theta$ **(1)** • Use of $F = mg$ **(1)** • B = 0.0786 T **(1)**	Example of calculation: $BIl = mg$ $\therefore B = \frac{5.65 \times 10^{-3}\ \text{kg} \times 9.81\ \text{N kg}^{-1}}{4.55\ \text{A} \times 15.5 \times 10^{-2}\ \text{m}} = 0.07859\ T$	**3**
1(b)	**MAX 3** A comment that makes reference to the following points: • High precision means a small spread of values **(1)** • High accuracy means close to the true value **(1)** • The student is actually referring to the resolution of the balance **(1)** • (The student should have stated) there was a low uncertainty in the value of the force **Or** a high resolution doesn't guarantee accuracy/precision **(1)**		**3**

(Total for Question 1 = 6marks)

7(a)	An explanation that makes reference to the following: • The time interval is very short **(1)** • the idea of a high sample rate (with the datalogger) **Or** (Percentage) uncertainty in measurement would be small (when using the datalogger). **(1)**	MP2 examples: time interval between measurements is small Many recordings/sec	**2**
7(b)(i)	• Correct time(s) read from graph **(1)** • Use of $v = \frac{s}{t}$ **(1)** • $v = 5900\ (\text{m s}^{-1})$ **(1)**	<u>Example of calculation:</u> $t = (1400 - 1000) \times 10^{-6}$ s $v = \frac{2L}{t} = \frac{2 \times 1.18\ \text{m}}{400 \times 10^{-6}\ \text{s}} = 5900\ \text{m s}^{-1}$	**3**
7(b)(ii)	• Substitution into $E = v^2 \rho$ ecf from (b)(i) **(1)** • $E = 2.7 \times 10^{11}$ Pa **(1)**	MP2 accept N m^{-2} for units 'show that value' gives $E = 2.8 \times 10^{11}$ Pa <u>Example of calculation:</u> $E = v^2\rho = (5900\ \text{m s}^{-1})^2 \times 7850\ \text{kg m}^{-3}$ $\therefore E = 2.73 \times 10^{11}$ Pa	**2**

(Total for Question 7 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
4(a)	• all I values should be recorded to the same number of decimal places **Or** all I values should be recorded to the same resolution **(1)**	Do not accept same number of significant figures	**1**
4(b)	• Ohm's law requires current to be (directly) proportional to the (applied) p.d **(1)** • Hence the line should pass through the origin **(1)** • (There is scatter around the line drawn by the student so) the correct line may be a curve **(1)** • Conclusion that this graph does not meet the conditions for Ohm's law so the student's statement is invalid **(1)**	For MP1 accept Ohm's law requires $I \propto V$ In MP2, credit students who check values from graph to see if I doubles when V doubles In MP3, credit students who draw a curve onto the graph MP4 dependent upon MP2 OR MP3	**4**
4(c)	• potential divider circuit diagram drawn as shown **(1)** • correctly incorporated into the given circuit **(1)**	 Switch not essential, accept potential divider with arrow drawn through resistor 	**2**

(Total for Question 4 = 7 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
7 (a)	• Use of $\Delta E = L\Delta m$ • Use of $\Delta E = mc\Delta\theta$ • $L = 2.1 \times 10^6$ J kg^{-1}	**(1)** **(1)** **(1)**	In MP1 Δm must be an attempt at a mass difference In MP2 allow any m, $\Delta\theta$ from the question data <u>Example of calculation</u> heat transfer as steam condenses = $(258.3\text{-}255.0)\times10^{-3}\text{kg} \times L$ heat transfer as steam cools = $3.3\times10^{-3}\text{kg}\times4190\text{ J kg}^{-1}\text{ K}^{-1}\times(100\text{-}26)\text{K}$ heat transfer as water is heated = $0.255\text{ kg}\times4190\text{ J kg}^{-1}\text{ K}^{-1}\times(26\text{-}18.5)\text{K}$ $\therefore 3.3\times10^{-3}\text{kg} \times L + 1023\text{ J} = 8013\text{ J}$ $\therefore L = \frac{8013\text{ J}\text{-}1023\text{ J}}{3.3\times10^{-3}\text{ kg}} = 2.12 \times 10^6\text{ J kg}^{-1}$	**3**
7(b)(i)	An explanation that makes reference to the following: • To bring tubing up to temperature (of steam) • So steam only condenses in the cup **Or** steam doesn't condense in the tubing	**(1)** **(1)**		**2**
7(b)(ii)	• Thermal energy will be transferred from the steam/tubing to the surroundings • Lagging/insulating/shortening the tubing	**(1)** **(1)**	Accept: • Thermal energy is transferred to the cup/ probe • These should have a small a heat capacity	**2**

(Total for Question 7 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	• Series circuit including power supply, heater and ammeter. **(1)** • Voltmeter connected in parallel with heater **(1)**		**2**
2(b)(i)	• Change in temperature and corresponding time **(1)** • Use of $P = \Delta E/\Delta t$ and $\Delta E = mc\Delta\theta$ **(1)** • c = 950 J kg^{-1} K^{-1} **(1)**	Example of calculation: $\frac{\Delta\theta}{\Delta t} = \frac{(36 - 16)\text{ K}}{(500 - 0)\text{ s}} = 0.04\text{ K s}^{-1}$ 37.5 W = 0.986 kg × c ×0.04 K s^{-1} c = 951 J kg^{-1} K^{-1}	**3**
2(b)(ii)	An explanation that makes reference to the following points: • In 240 s the temperature of the block rose by only 9.6 ºC **Or** It took 250 s for the temperature of the block to rise by 10 ºC. **(1)** • Hence there must have been energy transfer to the surroundings (by heating) **(1)**	For MP1 accept 9.5 ºC Accept it took 10 s longer For MP2 accept energy dissipated to the surroundings	**2**

(Total for Question 2 = 7 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
6(a)	• He should have moved the microphone over more in-phase positions (to determine multiple wavelengths) • This would reduce the uncertainty in the value (for *d*) (dependent upon MP1)	(1) (1)	**Alternative:** MP1: move microphone between antiphase positions MP2: as it is easier to judge when waves are in antiphase (peak corresponds to a trough)	**2**
6(b)	• No of divisions read from oscilloscope trace • Use of time base setting • Use of $f = 1/T$ • Use of $v = f\lambda$ • $v = 340\ \text{m s}^{-1}$	(1) (1) (1) (1) (1)	MP1: Must be for a recognised part of wave Example of calculation $T = 3 \times 0.20 \times 10^{-3}\ \text{s} = 6.0 \times 10^{-4}\ \text{s}$ $f = \dfrac{1}{6.0 \times 10^{-4}\ \text{s}} = 1.67 \times 10^{3}\ \text{Hz}$ $v = 1.67 \times 10^{3}\ \text{s}^{-1} \times 0.205\ \text{m} = 342\ \text{m s}^{-1}$	**5**

(Total for Question 6 = 7 marks)

Question Number	Acceptable Answer		Additional Guidance	
10(a)	• The first rubber band is too near the surface of the honey (so the ball won't be at its terminal velocity) • There is no method for checking that the ball is falling at terminal velocity (when he times)	**(1)** **(1)**	Accept statements for how procedure could be improved consistent with MP1 and MP2 e.g. there should be multiple bands for timing e.g. they haven't videoed the falling ball	**2**
10(b)(i)	• Mean time calculated • Use of $s = ut$ • $u = 0.039$ (m s^{-1})	**(1)** **(1)** **(1)**	Credit individual velocities and then mean velocity being calculated Example of calculation $t_{av} = \frac{6.40 + 6.35 + 6.36 + 6.38)\text{ s}}{4} = 6.37\text{ s}$ $u = \frac{0.25\text{ m}}{6.37\text{ s}} = 3.92 \times 10^{-2}\text{ m s}^{-1}$	**3**
10(b)(ii)	• Use of $\eta = \frac{2r^2 g(\rho_B - \rho_H)}{9v}$ • $\eta = 10.8$ (Pa s), so it is honey A	**(1)** **(1)**	Show that value gives 10.5 Pa s 10.7 Pa s if 0.0392 m s^{-1} used Allow ecf from (b)(i) Example of calculation $\eta = \frac{2 \times (5.50 \times 10^{-3})^2 \times 9.81\text{ m s}^{-2} \times (7750 - 1360)\text{ kg m}^3}{9 \times 3.9 \times 10^{-2}\text{ m s}^{-1}}$ $\therefore \eta = 10.8\text{ Pa s}$	**2**

(Total for Question 10 = 7 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	• Use of $\tan\theta = \frac{x}{D}$ **(1)** • Use of $d\sin\theta = n\lambda$ **(1)** • Use of $d = \frac{1}{\text{number of lines per metre}}$ **(1)** • λ = 520 nm so spacing of pattern was consistent **Or** x = 43.5 cm so spacing of pattern was consistent **Or** $d = 3.32 \times 10^{-6}$ m $\approx 3.33 \times 10^{-6}$ m, so spacing is consistent **Or** number of lines per mm = 301 ($\approx$300 mm^{-1}), so spacing is consistent **Or** $\theta = 8.97^{o} \approx 8.99^{o}$, so spacing is consistent **(1)**	Example of calculation $\tan\theta = \frac{0.435\text{ m}}{2.75\text{ m}} = 0.158$ $\theta = 8.99^{o}$ $d = \frac{1}{3 \times 10^{5}\text{ m}^{-1}} = 3.33 \times 10^{-6}$ m $\lambda = 3.33 \times 10^{-6}\text{ m} \times \sin 8.99^{o} = 5.20 \times 10^{-7}$ m	**4**
1(b)	**MAX 3** • The metre rule has a resolution of 0.1 cm **Or** The metre rule has a resolution not a precision **(1)** • Precision is how closely grouped (repeated) readings are **(1)** • Accuracy is how close the measured value is to the actual value **(1)** • Systematic error may shift measured values away from the actual values **Or** It may be difficult to judge the positions of the maxima **(1)**	MP4 Accept an example of systematic error e.g. a zero error **Or** a reference to parallax error	**3**

(Total for Question 1 = 7 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
2(a)	• Use of $P = \frac{V^2}{R}$	(1)	Use of $P = VI$ and $R = \frac{V}{I}$ to calculate R scores MP1 Use of $V = \epsilon - Ir$ scores MP2 and MP3 Allow use of potential divider equation for MP2 and MP3 Example of calculation $R = \frac{(12\ \text{V})^2}{40\ \text{W}} = 3.6\ \Omega$ $I = \frac{12\ \text{V}}{(3.6 + 0.5)\ \Omega} = 2.93\ \text{A}$ $V = 2.93\ \text{A} \times 3.6\ \Omega = 10.5\ \text{V}$ Allow $V = \left(\frac{3.6\ \Omega}{3.6\ \Omega + 0.50\ \Omega}\right) \times 12\ \text{V} = 10.5\ \text{V}$	4
	• Use of sum of e.m.fs = sum of p.d.s	(1)		
	• Use of $R = \frac{V}{I}$ to calculate a p.d.	(1)		
	• $V = 10.5$ V	(1)		

Question Number	Acceptable Answer	Additional Guidance	Mark
1(a)	• The ammeter is in series with the bulb and the voltmeter is in parallel with the bulb **Or** Adjusting the variable resistor will vary the current/p.d. **(1)** • The circuit may not be able to give a full range of applied p.d.s **Or** Reducing the variable resistance will place a p.d. across the bulb much larger than 3 V **(1)** • Comment on suitability consistent with stated characteristics of circuit **(1)**	Allow "the measurements of current and p.d. will be valid"	**3**
1(b)	• Precision is the closeness of agreement (consistency) between (repeated) measurements **(1)** • As the student has only taken a single value of current, the student cannot say the current is precise **(1)** • Accuracy is how close the measured value is to the true value **(1)** • The true value is not known, so the student cannot say the value will be accurate **Or** There may be a systematic error, so the student cannot say the value will be accurate **(1)**		**4**

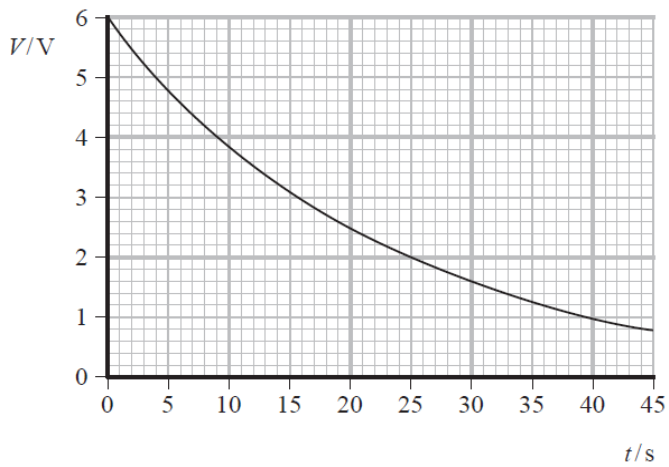
(Total for Question 1 = 7 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
5(a)(i)	• discards value for l_3 • l_m=85.7 (cm)	**(1)** **(1)**	MP2: answer to 1 d.p. only Example of calculation $l_m = \frac{85.5+86.0+85.5}{3} = 85.7$ cm	**2**
5(a)(ii)	• Use of $T = 2\pi\sqrt{\frac{\ell}{g}}$ • T=1.86 s	**(1)** **(1)**	ECF from (i) MP2: accept T = 1.9 s Example of calculation $T = 2\pi\sqrt{\frac{\ell}{g}} = 2\pi \times \sqrt{\frac{0.857\text{ m}}{9.81\text{ m s}^{-2}}} = 1.86$ s	**2**
5(b)	**Max 4** from 2 out of 3 pairs • The student should let the pendulum swing back and to before starting the stopwatch. • The first swing may be affected by the student pushing the bob as they release it • The student should use a (fiducial) marker at O • Easier to determine when it passes O • Time more oscillations • A longer time reduces (%) uncertainty (in T)	 **(1)** **(1)** **(1)** **(1)** **(1)** **(1)**	For each pair, the second marking point is dependent on the first marking point MP4: Accept the pendulum travelling fastest when it passes O	**4**

(Total for Question 5 = 8 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
2(a)	• Counting for 1 minute is too short a time **Or** he should count for at least 3 minutes **(1)** • He hasn't recorded the background count rate **(1)** • More than one reading taken and a mean calculated **Or** should have taken more than two readings (to calculate mean) **(1)**	To be marked holistically (with(b))	**3**
2(b)	**MAX 5** An explanation that makes reference to the following points: • The student has calculated the count rate rather than the activity of the source **(1)** • The counts haven't been corrected for background (so there is systematic error in his data) **(1)** • The GM tube is too far away from the source **(1)** • α-radiation won't reach the GM-tube as it only has a short range in air **(1)** • Radiation spreads out from the source, so not all the emitted radiation reaches the GM-tube **(1)** • GM tube won't detect all the gammas which enter it **(1)**	To be marked holistically (with(a))	**5**

(Total for Question 2 = 8 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)	• A pair of corresponding V and t values read from graph **(1)** • Use of $V = V_0 e^{-\frac{t}{RC}}$ **Or** Use of time constant = RC **(1)** • C = 270 μF **(1)** • Use of ±20% with 220 μF [Largest C = 264 μF, smallest C = 176 (μF)] **(1)** • Comparison of 264 (μF) [176 (μF) if their calculated C is too low] with calculated value of C from graph and conclusion consistent with this **(1)**	 Allow use of tangent at t = 0 to determine intercept on x-axis and obtain value for time constant; then calculate C gives MP1, MP2 and MP3 MP3:Value should be correct and have units Example of calculation $1.0 = 6.0e^{-\frac{40\ s}{82\times10^3\ \Omega\times C}}$ $\therefore \ln\left(\frac{1.0\ V}{6.0\ V}\right) = -\frac{40\ s}{82\times10^3\ \Omega\times C}$ $\therefore C = \frac{-40\ s}{-1.79\times82\times10^3\ \Omega} = 2.72\times10^{-4}\ C$ Largest value of capacitance = 1.2 × 220 μF = 264 μF	**5**

8(b)	• The data has to be collected in a short time **Or** Data logger has high sampling rate Or Data logger enables readings to be taken more frequently **(1)** • It would be difficult to read the voltmeter and stopwatch simultaneously **(1)** **(1)** • So the suggestion is correct [dependent on MP1 or MP2]	MP1: Data logger can take more readings in the time for capacitor to discharge	**3**

(Total for Question 8 = 8 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
1(a)	• Positions of mass holder not recorded • Data not recorded to the same sf/dp	(1) (1)	Accept reference to not all raw data being recorded/shown	2
1(b)	**MAX 3 from:** • Read the metre rule at eye level (to avoid parallax) • Bring the metre rule closer (to avoid parallax) • Use set square to read position of bottom of mass holder • Use plumb line to check that metre rule is vertical • Record positions of mass holder when loading and unloading and calculate mean value	 (1) (1) (1) (1) (1)	A labelled diagram could score MP3 and MP4 Accept valid alternatives to set square e.g. reference to marker on mass holder **or** add marker to line and position metre rule underneath line Accept valid alternatives to plumb line Accept repeat readings of position and calculate a mean	3
1(c)(i)	• The value of stress at which the fishing line starts to deform permanently/plastically **Or** the value of stress at which the fishing line continues to extend with no additional force	(1)	Accept point / strain for "value of stress" Accept line doesn't return to original length when force is removed	1
1(c)(ii)	• Use of $\varepsilon = \frac{\Delta x}{x}$ • (Maximum) extension (before yielding) is 8 cm, so line doesn't yield **Or** strain (at max extension) = 0.036, so line doesn't yield	(1) (1)	Example of calculation $\Delta x = 0.04 \times 2.0\ \text{m} = 0.08\ \text{m}$	2

(Total for Question 1 = 8 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
9(a)(i)	**MAX 3** • Intensity of light varies as an inverse square law **Or** reference to $I = \frac{P}{4\pi d^2}$ **(1)** • the light intensity would not increase uniformly (decreasing the distance as suggested) **(1)** • The student should decrease the distance at decreasing intervals **(1)** • The student should use a greater range (of distances, as lamp is not a point source of light) **(1)**		**3**
9(a)(ii)	An explanation that makes reference to the following points: **EITHER** • Carry out experiment under subdued lighting **(1)** • As the ambient lighting will increase the ammeter reading [dependent upon MP1] **(1)** **OR** • Take readings at eye level **(1)** • As this will reduce parallax error [dependent upon MP3] **(1)** **OR** • Take multiple readings of intensity and calculate a mean **(1)** • As this will reduce the effect of <u>random</u> error [dependent upon MP5] **(1)**	Allow: Keep the intensity of the lamp constant **Or** Keep angle of lamp constant As this would change the ammeter reading [dependent upon MP1	**2**

9(b)	An explanation that makes reference to the following points: • <u>Photons</u> incident upon LDR promoted electrons into conduction band **Or** <u>photons</u> incident upon LDR released conduction electrons **(1)** • Number of free electrons (per unit volume) increases **(1)** • Current $I = nqvA$ so the current increases **Or** $I \propto n$ so the current increases **(1)**	If no other marks scored, allow MAX 1 for resistance decreases and so current increases. Accept "charge carriers" for "free electrons"	**3**

(Total for Question 9 = 8 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
5(a)	• μ read from graph	**(1)**	Accept μ in the range 140 (m^{-1}) - 160 (m^{-1})	
	• Use of $I = I_0 e^{-\mu x}$	**(1)**		
	• I = 1.5 W m^{-2}	**(1)**	Accept answers that round to 1.4 W m^{-2} or 1.5 W m^{-2} dependent upon value of μ for MP3 Example of calculation: I=1.8 W m^{-2} × $e^{-150\ m^{-1} \times 1.4 \times 10^{-3}\ m}$ = 1.46 W m^{-2}	**3**
5(b)	• (for deoxygenated blood) μ is greater for red	**(1)**	Accept values for μ which show $\mu_{red} > \mu_{IR}$ for MP1	
	• hence more red is absorbed **Or** intensity is smaller for red **Or** $e^{-\mu x}$ is smaller for red	**(1)**	Allow numerical substitutions for MP2 and MP3	
	• So I/I_0 is smaller for red [dependent upon MP2]	**(1)**	Accept converse argument leading to same conclusion	**3**
5(c)	• Use of $\lambda_{max} T = 2.898 \times 10^{-3}$ m K	**(1)**	Ignore references to the wavelength of red light	
	• λ_{max} = 910 nm	**(1)**	Example of calculation: $\lambda_{max} = \frac{2.898 \times 10^{-3}\ \text{m K}}{3200\ \text{K}} = 9.06 \times 10^{-7}$ m	
	• Yes, because peak emission occurs at a wavelength close to 950 nm	**(1)**		**3**

(Total for Question 5 = 9 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>12(a)</td><td>
• Speed of impact is the same for both spheres (1)
• mass of sphere ∝ (diameter)^3 (1)
• $E_k = \frac{1}{2}mv^2$ so factor = 8 (1)
OR
• Final $E_k = \Delta E_{grav}$ (1)
• mass of sphere ∝ (diameter)^3 (1)
• $\Delta E_{grav} = mg\Delta h$, so factor = 8 (1)
</td><td>
For MP2 accept radius instead of diameter

A bald correct answer scores MP3 only

Example of calculation:
$\frac{m_2}{m_1} = \left(\frac{4\text{ cm}}{2\text{ cm}}\right)^3 = 8$
$\frac{E_{k2}}{E_{k1}} = \frac{m_2}{m_1} = 8$
</td><td>3</td></tr>
<tr><td>*12(b)</td><td>
This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The table shows how the marks should be awarded for indicative content and lines of reasoning.
<table>
<tr><th>IC points</th><th>IC mark</th><th>Max linkage mark available</th><th>Max final mark</th></tr>
<tr><td>6</td><td>4</td><td>2</td><td>6</td></tr>
<tr><td>5</td><td>3</td><td>2</td><td>5</td></tr>
<tr><td>4</td><td>3</td><td>1</td><td>4</td></tr>
<tr><td>3</td><td>2</td><td>1</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>0</td><td>2</td></tr>
<tr><td>1</td><td>1</td><td>0</td><td>1</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td></tr>
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<table>
<tr><td></td><td>Number of marks awarded for structure of answer and sustained line of reasoning</td></tr>
<tr><td>Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr>
<tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr>
<tr><td>Answer has no linkages between its points and is unstructured</td><td>0</td></tr>
</table>
</td><td></td></tr>
</table>

	Indicative content: • The table shows that increasing the drop height does increase the crater diameter • Increasing the drop height increases the impact velocity/E_k • Because there is a greater acceleration time **Or** because there is a greater transfer of GPE to KE • The table does not show that increasing the sphere diameter (always) increases the crater diameter • For smaller spheres (from 2 to 4 cm), increasing sphere diameter does increase crater diameter **Or** for bigger spheres (from 4 to 6 cm), increasing the sphere diameter has little effect on crater diameter • More data is needed for firmer conclusions	For IC3 accept reference to an appropriate equation For IC5 accept "no effect" or "inconsistent effect" for "little effect"	**6**

(Total for Question 12 = 9 marks)

Question Number	Acceptable Answer		Additional guidance	Mark
12(a)	• Uses a micrometer screw gauge • Repeats readings at different places/orientations and calculates a mean	(1) (1)	Accept digital vernier callipers	2
12(b)	• Use of $R = \frac{V}{I}$ • Use of $A = \frac{\pi d^2}{4}$ • Use of $R = \frac{\rho l}{A}$ • $\rho = 1.1 \times 10^{-6}\ \Omega\,\text{m}$	(1) (1) (1) (1)	Example Calculation R= 1.96 V / 0.57 A R = 3.44 Ω $A = (\pi \times (0.58 \times 10^{-3}\ \text{m})^2) / 4$ $A = 2.64 \times 10^{-7}\ \text{m}^2$ $\rho = (3.44\ \Omega \times 2.64 \times 10^{-7}\ \text{m}^2) / 0.835\ \text{m}$ $\rho = 1.1 \times 10^{-6}\ \Omega\,\text{m}$	4
12(c)	• The area is determined by d^2 • Percentage uncertainty in diameter is doubled. %U = 2 % • The student's statement is incorrect as percentage uncertainty in diameter squared is the greatest percentage uncertainty	(1) (1) (1)	Example Calculation %U(diameter^2) = 2 × 0.8 % = 1.6 % MP3 dependent on MP1 and 2	3

(Total for Question 12 = 9 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
4(a)(i)	• The detector area exposed to γ-radiation is larger in the set-up of Student A **(1)** • So the count (rate) will be greater (at a given distance from the source) **(1)** • Hence (the percentage uncertainty will be smaller for) Student A **(1)**	Alternative MP1 and MP2 • *d* should be measured to the middle of the counter (1) • The error (or uncertainty) in *d* is reduced in set-up of Student A (1) MP3 dependent on MP1 **and** MP2	**3**
4(a)(ii)	An explanation that makes reference to the following points: • Record the background count (rate) and subtract from recorded count (rate) **(1)** • Gives count (rate) of source only **Or** As background count adds to the count from the source **(1)** • Record the count for a longer time **(1)** • As this will increase the total count (at a given distance) **(1)**	Allow "Adds a systematic error" Alternative MP3 and MP4 • Repeat the measurement of the count and calculate a mean (1) • As radioactive decay is random (1)	**4**

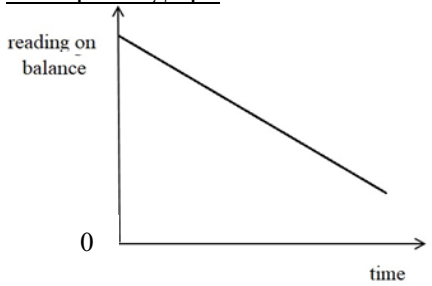
4(b)	An explanation that makes reference to the following points: • Place an aluminum sheet between the source and the detector **(1)** • As this will absorb/block the alpha and beta radiation emitted by the source **(1)**	Allow up to 3 mm of lead	**2**

(Total for Question 4 = 9 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
5(a)	• Use a micrometer screw gauge **(1)** • Check (and correct) for zero error **Or** Use the ratchet on the micrometer **(1)** • Measure diameter at different positions along wire and calculate a mean **Or** Measure diameter at different orientations and calculate a mean **(1)** • Calculate cross sectional area using $\frac{\pi d^2}{4}$ **Or** Calculate radius and then use πr^2 **(1)**	Allow digital calipers not vernier calipers	**4**
5(b)(i)	An explanation that makes reference to the following points: • Electrons collide with (lattice) ion and transfer energy **Or** Current in wire causes temperature of wire to increase **(1)** • So the amplitude of vibration (of the lattice ions) increases **(1)** • Electrons make more frequent collisions (with lattice ions), so the resistance increases **(1)**		**3**

5(b)(ii)	Max **TWO** from: • (For a black body radiator) Stefan(-Boltzmann) law applies **Or** (For a black body radiator) $L = \sigma AT^4$ **(1)** • The rate of energy transfer from the wire is determined by its surface area **(1)** • Increasing the length increases the surface area, so more energy is radiated away (and the temperature does not change) **(1)**		**2**

(Total for Question 5 = 9 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)	• The ammeter should be in series with the heater **Or** ammeter is not measuring current through the heater **(1)** • The range of the ammeter (mA) is too small **(1)**		2
3(b)(i)	• Both axes labelled **(1)** • Straight line with negative gradient **(1)** • Reading on balance does not cut the time axis **(1)**	MP3 dependent upon MP2 Example of graph  	3
3(b)(ii)	• Use of $W = VI$t **(1)** • Use of $\Delta E = mL$ **(1)** • $L = 2.4 \times 10^6$ J kg^{-1} **(1)**	Example of calculation $W = 12\text{ V} \times 4.2\text{ A} \times (6 \times 60)\text{s} = 1.81 \times 10^4\text{ J}$ $L = \frac{1.81 \times 10^4\text{J}}{7.5 \times 10^{-3}\text{kg}} = 2.41 \times 10^6\text{ J kg}^{-1}$	3
3(b)(iii)	An explanation that makes reference to the following points: • Energy is transferred (from the beaker/heater/water) to the surroundings **(1)** • So the calculated value of L will be larger than the true value **(1)**		2

(Total for Question 3 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
5(a)(i)	• Changes (in recorded length) due to the support bending are minimised **Or** changes (in recorded length) due to temperature are minimised **Or** it allows use of a vernier scale (to determine extension) **(1)**		**1**
5(a)(ii)	• To keep the reference wire taut/straight **Or** to keep the reference wire under tension **(1)**		**1**
5(b)	An explanation that makes reference to the following points: • A thin wire has a large stress (for a given load) **(1)** • A long/thin wire has a large extension (for a given stress) **(1)** • Hence the percentage uncertainty in the length/extension is reduced **(1)**		**3**
5(c)	• Calculates A **(1)** • Determine gradient **(1)** • Substitutes $\sigma = \frac{F}{A}$ **and** $\varepsilon = \frac{\Delta x}{x}$ into $E = \frac{\sigma}{\varepsilon}$ **(1)** • Uses $E = \frac{1}{\text{gradient}} \times \frac{x}{A}$ **(1)** • $E = 1.1 \times 10^{11}$ N m^{-2} **(1)**	Example of calculation $A = \frac{\pi \times (5.60 \times 10^{-4}\text{m})^2}{4} = 2.46 \times 10^{-7}\text{m}^2$ $E = \frac{F/A}{\Delta x/x} = \frac{F}{\Delta x} \times \frac{x}{A}$ $\text{Grad} = \frac{\Delta x}{F} \therefore E = \frac{1}{\text{gradient}} \times \frac{x}{A}$ $\text{Grad} = \frac{(3.6 - 0.75) \times 10^{-3}\text{m}}{(32.0 - 5)\text{ N}}$ $= 1.06 \times 10^{-4}\text{ m N}^{-1}$ $\therefore E = \frac{1}{1.06 \times 10^{-4}\text{ m N}^{-1}} \times \frac{2.75\text{ m}}{2.46 \times 10^{-7}\text{m}^2}$ $\therefore E = 1.057 \times 10^{11}\text{ N m}^{-2}$	**5**

(Total for Question 5 = 10 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
5(a)	• Time a number of (complete) oscillations calculate a mean time period **(1)** • This reduces the effect of random error (dependent on MP1) **(1)** • Allow oscillation to settle before starting to time. **(1)** • Use a (fiducial) marker (so easier to see when trolley passes a point) **(1)** • Use the mid-point of the oscillation (for timing), **(1)** • Trolley is travelling fastest at mid-point, so effect of reaction time is reduced. **(1)**	Accept description of how to determine a mean – don't need to see the word "mean" Accept reaction time for random error, also accept reference to reducing percentage uncertainty Accept equilibrium/undisplaced position For MP6 allow use a datalogger to eliminate effect of reaction time [not dependent upon MP5]	**6**
5(b)	• Substitutes into equation for mass on spring to give $T = 2\pi\sqrt{\frac{M+m}{k}}$ **(1)** • $T^2 = \frac{4\pi^2}{k}m + \frac{4\pi^2 M}{k}$ **(1)** • Identify gradient as $4\pi^2/k$ (and calculate a value for k) **(1)** • Identify y-intercept as $4\pi^2 M/k$ (and calculate a value for M) **(1)**		**4**

(Total for Question 5 = 10 marks)

Question Number	Acceptable Answer		Additional Guidance	Mark
6(a)	• Series circuit with power supply, heater and ammeter. • Voltmeter connected in parallel with heater	(1) (1)		2
6(b)	• Use of $P = VI$ • Calculation of gradient • Gradient = $\frac{\Delta m}{\Delta t}$ • Use of $\Delta E = mL$ and $P = \frac{\Delta E}{\Delta t}$ • $L = 2.30 \times 10^6$ (J kg^{-1}) • Comparison of calculated value for L with values in table and appropriate conclusion. • But not all of the energy supplied to the liquid will be used to boil the liquid **Or** thermal energy will be transferred to surroundings	(1) (1) (1) (1) (1) (1) (1)	For MP2 and MP3 credit Δm read from graph and used with corresponding Δt value For MP3 and MP4, credit $L = \frac{VI}{\text{gradient}}$ Answers in the range $(2.26 – 2.34) \times 10^6$ J kg^{-1} Example of calculation: $\text{grad} = \frac{(211\text{-}155)\times10^{-3}\text{ kg}}{(0\text{-}600)\text{ s}} = 9.33 \times 10^{-5}\text{ kg s}^{-1}$ $\therefore \frac{\Delta m}{\Delta t} = 9.33 \times 10^{-5}\text{ kg s}^{-1}$ $P = 20.5\text{ V} \times 10.5\text{ A} = 215\text{ W}$ $\therefore L = \frac{215\text{ W}}{9.33\times10^{-5}\text{kg s}^{-1}} = 2.30\times10^6\text{ J kg}^{-1}$	7

6(c)	• Use lagging to insulate the container from the surroundings **(1)** • So that a greater proportion of the energy supplied is used to boil the liquid **(1)** **Or** • Use a heater with a higher electrical power **(1)** • So that a shorter time is needed to boil the liquid **(1)**	Accept "to minimise heat loss to the surroundings"	**2**

(Total for Question 6 = 11 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>*9(a)</td><td>This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.

Indicative content:

IC1 Both circuits are suitable because they allow readings of p.d./current for the lamp

IC2 For circuit 1 the minimum p.d. across the lamp is 0 V (when the slider is at the left)
Or For circuit 2 the minimum p.d. across the lamp is greater than 0 V

IC3 For circuit 1 the maximum p.d. across the lamp is the supply p.d (when the slider is at the right)

IC4 For circuit 2 adjusting the resistor changes the circuit resistance (so the current is varied)
Or for circuit 2 the battery p.d. is shared between lamp and variable resistor

IC5 So for circuit 2 the minimum p.d. depends upon the resistance of the variable resistor,

IC6 Circuit 1 is better because it allows a bigger range
Or Circuit 1 is better because it allows p.d.s down to 0 V to be used</td><td>Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.

<table><tr><th>Number of indicative marking points seen in answer</th><th>Number of marks awarded for indicative marking points</th></tr><tr><td>6</td><td>4</td></tr><tr><td>5–4</td><td>3</td></tr><tr><td>3–2</td><td>2</td></tr><tr><td>1</td><td>1</td></tr><tr><td>0</td><td>0</td></tr></table>
<table><tr><th></th><th>Number of marks awarded for structure of answer and sustained line of reasoning</th></tr><tr><td>Answer shows a coherent and logical structure with linkages and fully sustained lines of reasoning demonstrated throughout</td><td>2</td></tr><tr><td>Answer is partially structured with some linkages and lines of reasoning</td><td>1</td></tr><tr><td>Answer has no linkages between points and is unstructured</td><td>0</td></tr></table>
Total marks awarded is the sum of marks for indicative content and the marks for structure and lines of reasoning
<table><tr><th>IC points</th><th>IC mark</th><th>Max linkage mark</th><th>Max final mark</th></tr><tr><td>6</td><td>4</td><td>2</td><td>6</td></tr><tr><td>5</td><td>3</td><td>2</td><td>5</td></tr><tr><td>4</td><td>3</td><td>1</td><td>4</td></tr><tr><td>3</td><td>2</td><td>1</td><td>3</td></tr><tr><td>2</td><td>2</td><td>0</td><td>2</td></tr><tr><td>1</td><td>1</td><td>0</td><td>1</td></tr><tr><td>0</td><td>0</td><td>0</td><td>0</td></tr></table></td><td>6</td></tr>
<tr><td>9(b)(i)</td><td>• Use of $R = V/I$ (1)
• $V = 2.2$ V (1)</td><td><u>Example of calculation</u>
$V = 17.5 \times 10^{-3}\ \text{A} \times 560\ \Omega = 9.8\ \text{V}$
$\therefore V_{\text{LED}} = (12 - 9.8)\text{V} = 2.2\ \text{V}$</td><td>2</td></tr>
</table>

9(b)(ii)	An explanation that makes reference to the following points: **Either** • The effective resistance of the combination is less than the resistance of the lamp **(1)** • The combination has a smaller fraction of the total circuit resistance **(1)** • Hence a smaller fraction of the supply p.d. falls across the lamp **(1)** **OR** • The effective resistance of the combination is less than the resistance of the lamp **(1)** • The total circuit resistance decreases and the current increases **(1)** • So the p.d. across the resistor increases (so the p.d. across the lamp must decrease) **(1)** **OR** **(1)** • Current flows through voltmeter • So circuit current increases **(1)** **Or** current through resistor increases **(1)** • So the p.d. across the resistor increases		**3**

(Total for Question 9 = 11 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
9(a)(i)	An explanation that makes reference to the following points: • Use a (fiducial) marker **(1)** • Placed at the equilibrium position (of cantilever) **(1)** • (This will reduce timing errors) as end of cantilever is moving fastest at the equilibrium position **(1)**		3
9(a)(ii)	An explanation that makes reference to the following points: • Time a larger number of oscillations **(1)** • This will increase the total time recorded **(1)**		2

9(b)	• Calculation of average time (period) **(1)** • Use of $T^2 \propto \frac{ML^3}{E}$ **(1)** • Calculates $\frac{E_1}{E_2}$ **(1)** • Calculates $\frac{E_{\text{spruce}}}{E_{\text{cedar}}}$ **(1)** • $\frac{E_1}{E_2}$ =1.22 **and** $\frac{E_{\text{spruce}}}{E_{\text{cedar}}}$ = 1.25 **(1)** • As 1.22 is close to 1.25, the metre rule must be made from spruce **and** half-metre rule from cedar **Or** Conclusion based on comparison of calculated values from using calculated ratio **(1)**	Example of calculation $T_1 = \frac{14.69\text{ s} + 14.64\text{ s} + 14.76\text{ s})/3}{5} = 2.94\text{ s}$ $T_2 = \frac{5.33\text{ s} + 5.40\text{ s} + 5.24\text{ s})/3}{5} = 1.06\text{ s}$ $\left(\frac{T_1}{T_2}\right)^2 = \left(\frac{L_1}{L_2}\right)^3 \times \frac{E_2}{E_1} \quad \therefore \frac{E_1}{E_2} = \left(\frac{L_1}{L_2}\right)^3 \times \left(\frac{T_2}{T_1}\right)^2$ $\therefore \frac{E_1}{E_2} = \left(\frac{0.95\text{ m}}{0.45\text{ m}}\right)^3 \times \left(\frac{1.06\text{ s}}{2.94\text{ s}}\right)^2 = 1.22$ $\frac{E_{\text{spruce}}}{E_{\text{cedar}}} = \frac{9.6\text{ GPa}}{7.7\text{ GPa}} = 1.25$ Alternative MP4 and MP5 • Calculates $E_{\text{cedar}} \times \frac{E_1}{E_2} = E_{\text{spruce}}$ • $\frac{E_1}{E_2}$ =1.22 **and** E_{spruce} = 9.5 (or E_{cedar} = 7.9)	**6**

(Total for Question 9 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	• connect thermistor to an ohmmeter to measure its resistance **(1)** • Use a water bath eg beaker of water and immerse the thermistor **(1)** • measure the temperature of the water using a thermometer **(1)** • vary temperature and measure the resistance at fixed intervals **(1)** • Thermometer held in retort stand to make beaker stable **Or** Leads clamped to make beaker stable **(1)** • detailed point such as stir water **(1)**	alt based on ammeter/voltmeter combination alternative methods eg vary *T* by using boiling water from a kettle and allow to cool alternative safety: plenty of space around apparatus **Or** Safety glasses in case of splashes stand **Or** heatproof mat as boiling water alternative detail: ensure eye level with thermometer **Or** adjust ohmmeter to give maximum sig fig without final figure varying randomly **Or** allow time for thermistor to reach water temperature **Or** keep thermometer and thermistor close to one another	**6**

12(b)	• resistance values have been taken every 10° take more values say at 25 °C and 35 °C when *R* is changing more **(1)** • Widen the range – can find *R* up to 100 °C ie boiling water Or decrease *t* below room temperature by adding ice **(1)** • Repeat experiment measuring *R* at the same temperatures then average *R*'s **(1)**		**2Max**
12(c)	• Increased temperature causes more energy transfer to lattice ions / atoms **(1)** • More charge carriers released / available **(1)** • $I = nAvq$, so relative increase in *I* **(1)** • Reference to $R = V / I$ to justify decrease in *R* **(1)**	Or reverse argument	**4**

(Total for Question = 12 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)	A description that makes reference to the following: • (Remove the source and) record background count for specified time and subtract from equivalent quantity **(1)** • Divide by time to give a count rate. **(1)**	There needs to be two clear steps. Subtract a count from a count, or a count rate from a count rate and divide a count by time to obtain a count rate.	**2**
10(b)(i)	**Either** • The GM-tube has a low efficiency for γ-ray detection **Or** there is an increased area exposed to γ-rays **(1)** • (So) placing the tube side on to the radiation would increase the count rate **(1)** **Or** • The γ-radiation could be detected anywhere inside the GM-tube **(1)** • So placing the tube side on to the radiation would reduce the uncertainty in the distance measurement **(1)**	For low efficiency, accept GM tube poor at detecting γ-rays.	**2**
10(b)(ii)	• Record the count (at least) twice and then determine an average count rate **Or** record the count for a much longer time **(1)** • This reduces the effect of (random) errors in the measurement of the count rate **(1)**		**2**

10(c)(i)	• Mean straight line with positive intercept on the y-axis **(1)**		**1**
10(c)(ii)	• $C = \frac{K}{4\pi d^2}$ used to show $\frac{1}{\sqrt{C}} \propto d$ **(1)** **Or** identifies gradient as $\sqrt{\frac{4\pi}{K}}$ which is constant **(1)** • Since graph is a straight line, data is consistent with this **(1)** • However, line doesn't pass through the origin • This indicates a <u>systematic</u> error in measuring the distance **(1)**		**4**
10(d)	• α-particles would only travel a few cm (in air), and so wouldn't reach the GM-tube **(1)** • β-particles would probably not pass through the sides of the GM-tube, and so wouldn't be detected so suggestion is correct. **(1)**	Accept a reference to α-particles not passing through the side of the tube (even if they reached it when d was small) and so not contributing to the count (rate) For 2 marks expect a valid conclusion, as well as a statement of the likelihood of the α-particles and β-particles contributing to the count (rate)	**2**

(Total for Question 10 = 13 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)	An explanation that makes reference to the following points: • Uncertainty in each reading = 0.05 cm • Uncertainty in r is 2 × uncertainty in each reading **(1)** • Hence percentage uncertainty = 0.8 % **(1)** **(1)**	Example of calculation: $\%\ \text{uncertainty} = \frac{0.1\ \text{cm}}{(17.5\text{-}5.0)\ \text{cm}} \times 100\ \% = 0.8\ \%$ Accept statement that uncertainty in r = 0.1 cm for MP2	**3**
3(b)(i)	• To reduce the effect of random errors **(1)**		**1**
3(b)(ii)	• Use of data to calculate mean value **(1)** • Use of half range **(1)** **Or** Use of greatest deviation from mean • % uncertainty in range 5 % to 6% consistent with student's working (1 or 2 SF) **(1)**	Example of calculation: $\omega_{av} = \frac{(0.112+0.116+0.118+0.123+0.125)}{5}$ $= 0.119\ \text{rad s}^{-1}$ Half range value = $\frac{0.125\ \text{mm} - 0.112\ \text{mm}}{2} = 0.0065$ ∴ % uncertainty = $\frac{0.0065\ \text{mm}}{0.119\ \text{mm}} \times 100\ \% = 5.5\ \%$ Use of greatest deviation from mean gives 5.9 %	**3**
3(b)(iii)	• % uncertainty in ω is doubled **(1)** • Add % uncertainty in r **(1)** • % uncertainty = 11 % to 13% consistent with student's working (2 or 3 SF)(ecf from (b)(ii)) **(1)**	Don't penalise sf in both (ii) **and** (iii) Example of calculation: % uncertainty = 5% + 5% + 1% = 11%	**3**
3(c)	An explanation that makes reference to the following points: • The centripetal force is provided by friction **(1)** • There is a max (frictional) force **Or** (frictional) force is the same when coin starts to slide **(1)** • $F = m\omega^2 r$ so as r increased ω decreased **(1)**	For MP3 accept ω^2 for ω	**3**

(Total for Question 3 = 13 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
8(a)(i)	• Use of $P = VI$ **(1)** • P = 1900 W (1.9 kW) **(1)**	Example of calculation P=230 V × 8.20 A = 1890 W	**2**
8(a)(ii)	• Use of $\Delta E = mc\Delta\vartheta$ • Use of $P = \frac{\Delta E}{\Delta t}$ **(1)** • Δt = 112 s or 113 s ECF from (a)(i) **(1)** **(1)**	Example of calculation $\Delta E = 0.655\ \text{kg} \times 4190\ \text{J kg}^{-1}\text{K}^{-1} \times (100 - 22.5)\text{K}$ $\Delta E = 2.13 \times 10^5\ \text{J}$ $\Delta t = \frac{2.13 \times 10^5\text{J}}{1890\ \text{W}} = 112.5\ \text{s}$	**3**
8(b)(i)	• After a short time of boiling in the flask, all the apparatus would be at 100 °C. **Or** so energy is not being used to heat up the flask **Or** so steam won't condense in the flask **(1)**		**1**
8(b)(ii)	• Use of $\Delta E = mL$ **(1)** • Use of $P = \frac{\Delta E}{\Delta t}$ **(1)** • 1720 W (1.72 kW) **(1)**	Example of calculation $\frac{\Delta m}{\Delta t} = \frac{95 \times 10^{-3}\ \text{kg}}{125\ \text{s}} = 7.6 \times 10^{-4}\ \text{kg s}^{-1}$ $\frac{\Delta E}{\Delta t} = 7.6 \times 10^{-4}\ \text{kg s}^{-1} \times 2.26 \times 10^6\text{J kg}^{-1}$ $P = 1720\ \text{J s}^{-1}$	**3**
8(b)(iii)	• Comparison of answer to (a)(i) with answer to (b)(ii) **(1)** • Not all of the energy from the heater is used to turn water from liquid state into vapour **Or** energy is being used to heat the heat exchanger **Or** not all the steam condenses in the heat exchanger **(1)** • Some energy is transferred to the surroundings **(1)**	e.g. rate at which thermal energy is supplied to the water in the flask is greater than rate at which thermal energy is removed from the water in the heat exchanger. If answer for (b)(ii) is bigger than 2 kW,1 mark for correct comparison can be scored.	**3**
8(c)	• By lagging the flask (to reduce energy transfer to the surroundings) **(1)**		**1**

(Total for Question 8 = 13 marks)

Question Number	Acceptable answers		Additional guidance	Mark
12(a)	• (Measure diameter) using micrometer / digital calipers	(1)		3
	• Repeat measurements and calculate the mean	(1)		
	• Take measurements at different points (along the wire) **or** at different orientations	(1)		
12(b)(i)	• Substitutes stress $= \frac{F}{A}$ and strain $= \frac{\Delta x}{x}$ into $E = \frac{stress}{strain}$	(1)		2
	• Identifies gradient as $\frac{F}{\Delta x}$	(1)		
12(b)(ii)	• Calculates gradient of straight section	(1)		4
	• Use of $E = gradient \times \frac{x}{A}$	(1)		
	• E = 1.2 to 1.3 $\times$ 10^{11} N m^{-2}	(1)	Example of calculation Gradient $= \frac{33}{7 \times 10^{-3}}$ = 4600 - 4900 E = 1.24 $\times$ 10^{11} N m^{-1} = 124 GPa copper	
	• Wire is made from copper because 117 GPa is closest to the calculated value **Or** Correct conclusion of the metal consistent with candidate's calculated value	(1)		
12(b)(iii)	• Use a smaller (maximum) force/load	(1)		4
	• To avoid exceeding the limit of proportionality **Or** As the breaking force of a thinner wire is smaller	(1)		
	• Use small(er) increments in the force/load	(1)		
	• To obtain more readings (before the elastic limit is reached) **Or** to obtain enough readings (in the linear part of the graph)	(1)		

(Total for Question 12 = 13 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
6(a)	• Time a number of (complete) oscillations and divide this time by the number of (complete) oscillations **(1)** • Repeat measurement (of time) **and** determine a mean value **(1)** • Use a (fiducial) marker (so easier to see when trolley passes a particular point) **(1)** • Time from the mid-point of the oscillation **Or** Wait for oscillation to settle before starting to time **(1)**	[Allow 1 mark for reference to using light gates and a data logger if no other marks awarded]	**4**
6(b)	• T read from oscilloscope trace **(1)** • Use of time-base setting **(1)** • Use of $\omega = 2\pi / T$ **Or** Use of $f = 1/T$ **(1)** • Use of $v = (-)A\omega \sin \omega t$ **(1)** • $v = 0.75$ m s^{-1} **(1)**	Use of $\omega = 2\pi f$ Example of calculation $T = 2 \text{ div} \times 250 \text{ ms div}^{-1} = 500 \text{ ms}$ $\omega = \frac{2\pi}{0.50 \text{ s}} = 12.6 \text{ rad } s^{-1}$ $v = 6.0 \times 10^{-2} \times 12.6 \text{ rad s}^{-1} = 0.754 \text{ m s}^{-1}$	**5**

6(c)(i)	An explanation that makes reference to the following points: • (As the frequency is increased) the amplitude increases to a maximum at a frequency of 2 Hz (and then decreases) **(1)** • This is the natural frequency (of oscillation) of the trolley **(1)** • When the vibrator drives the trolley at its natural frequency there is a maximum transfer of energy (from the vibrator to the trolley) **(1)** • This is resonance **(1)**		**4**
6(c)(ii)	• Use of $T = 2\pi\sqrt{\frac{m}{k}}$ **(1)** • $k = 140$ N m^{-1} **(1)**	Example of calculation $0.5\text{ s} = 2\pi \times \sqrt{\frac{0.87\text{ kg}}{k}}$ $\therefore k = \frac{4\pi^2 \times 0.87\text{ kg}}{(0.5\text{ s})^2} = 137\text{ N m}^{-1}$	**2**

(Total for Question 6 = 15 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)(i)	**MAX 4** • It's difficult to measure from the same position on the spring each time **(1)** • Ruler may move between readings • There may be parallax error in reading positions **(1)** • The student has only taken one measurement for each added mass **(1)** • Hence this method would not produce accurate values **(1)** (dependent upon at least one from MP1 ¬ MP4)	Mark (i) and (ii) holistically	**5**
10(a)(ii)	**MAX 5** • Attach a pointer to the bottom of the spring **Or** take measurements from bottom of mass holder **(1)** • Bring metre rule closer to the spring **(1)** • Take measurements from the metre rule as masses are added and as masses are removed **(1)** • Calculate a mean extension for each mass **(1)** • Method to ensure metre rule is vertical **(1)** • Method to reduce parallax error **(1)**	Mark (i) and (ii) holistically e.g. use of a set square, lining up against a vertical, use of spirit level e.g. take reading at eye level	**5**
10(b)(i)	• Ignoring mass of holder / spring when determining the oscillating mass **(1)**		**1**

10(b)(ii)	• Using a data logger (and light gate) would eliminate reaction time **(1)** • So the uncertainty in the measurement (of the time) would be reduced **(1)** • Not easy to measure timings for multiple swings/oscillations with a data logger **(1)**	MP2 (dependent upon MP1	**3**
10(b)(iii)	• Identify gradient as $\frac{4\pi^2}{k}$ **(1)** • Determine gradient of graph **(1)** • k = 17.8 N m^{-1} [17.5 → 18.5] **(1)**	Example of calculation Gradient = 2.21 s^2 kg^{-1} $k = \frac{4\pi^2}{2.21\ \text{s}^2\ \text{kg}^{-1}} = 17.8\ \text{N m}^{-1}$	**3**
10(c)	• Timing a large number of oscillations minimised the percentage uncertainty in the measurement **(1)** • Repeating each timing measurement and calculating a mean minimised the effect of random errors **(1)** • Taking a repeat measurement allowed a check for gross timing errors. **(1)**		**3**

(Total for Question 10 = 20 marks)

Question Number	Acceptable Answer		Additional Guidance	
13(a)	• Waves are reflected from the opposite bridge • Waves meet in phase (at mid-point of wire) and superpose • Constructive interference occurs giving a maximum displacement	**(1)** **(1)** **(1)**		**3**
13(b)(i)	• Wear safety glasses (to protect eyes from breaking wire) **Or** wear suitable footwear (to protect feet from falling masses) **Or** place sand tray under masses (to catch them if they fall)			**1**
13(b)(ii)	• $\lambda = 2L$ substituted into $v = f\lambda$ • v substituted into $v = \sqrt{\frac{T}{\mu}}$ • Correct re-arrangement into $y = mx + c$ format	**(1)** **(1)** **(1)**	$v = f\lambda$ and $\lambda = 2L$ so $v = 2fL$ $v = \sqrt{\frac{T}{\mu}}$, so $4f^2L^2 = \frac{T}{\mu}$ $L^2 = \left(\frac{T}{4\mu}\right).\frac{1}{f^2}$, so gradient is $\frac{T}{4\mu}$	**3**
13(b)(iii)	• Gradient calculated • Use of gradient = $\frac{T}{4\mu}$ • $\mu = 1.8$ (g m^{-1}) • SWG consistent with their calculated value of μ (24 swg)	**(1)** **(1)** **(1)** **(1)**	Example of calculation gradient $= \frac{(0.043 - 0)\text{m}^2}{(15.0 - 0.0) \times 10^{-6}\text{s}^2} = 2.87 \times 10^3\text{m}^2\text{s}^{-2}$ $\mu = \frac{2.1\text{ kg} \times 9.81\text{ m s}^{-2}}{4 \times 2.87 \times 10^3\text{m}^2\text{s}^{-2}} = 1.79 \times 10^{-3}\text{ kg m}^{-1}$ $\therefore \mu = 1.79\text{ g m}^{-1}$	**4**

13(c)(i)	An explanation that makes reference to the following points: **Either** • Take readings in different positions/orientations along the wire (and calculate a mean) **(1)** • As wire diameter may not be uniform **(1)** **OR** • Check (and correct for) for zero error **(1)** • Zero error reduces the accuracy of the measurement **Or** Zero error moves the value away from the true value **(1)**	**Accept:** use ratchet to close up micrometer to avoid squashing the wire MP2 accept cross section for diameter MP2: accept to reduce the effect of random error MP2 accept systematic error not changed by repeat measurements	**2**
13(c)(ii)	• Use of half range value to calculate % uncertainty in d **Or** use of max value from mean to calculate % uncertainty in d **(1)** • % uncertainty in area = 2 × (% uncertainty in d) **(1)** • Calculation of % uncertainty in density **(1)** • % uncertainty in density added to % uncertainty in area **(1)** • Use of $\mu = \frac{m}{L}$ with $\rho = \frac{m}{V}$ **(1)** • $\mu = 2.2 \times 10^{-3}$ kg m^{-1} ± 0.2×10^{-3} kg m^{-1}, so the stated value is supported by the student's data **(1)**	Example of calculation $\bar{d} = \frac{(0.55 + 0.59 + 0.57 + 0.58)\text{ mm}}{4} = 0.57\text{ mm}$ % uncertainty in $d = \frac{0.02\text{ mm}}{0.57\text{ mm}} \times 100 = 3.5$ ∴ % uncertainty in area = $2 \times 3.5 = 7.0$ % uncertainty in density $= \frac{200\text{ kg m}^{-3}}{8700\text{ kg m}^{3}} \times 100 = 2.3$ % uncertainty in μ = 2.3 + 7.0 = 9.3 $\mu = \frac{m}{L} = \frac{\rho AL}{L} = 8700\text{ kg m}^{-3} \times \pi \times \left(\frac{0.57 \times 10^{-3}\text{ m}}{2}\right)^2$ $\mu = 2.2 \times 10^{-3}\text{ kg m}^{-1}$ Range $= \pm\frac{9.3}{100} \times 2.2 \times 10^{-3}\text{ kg m}^{-1} = 2.05 \times 10^{-4}\text{ kg m}^{-1}$ So $2.0 \times 10^{-3}\text{kg m}^{-1} < \mu < 2.4 \times 10^{-3}\text{ kg m}^{-1}$	**6**

(Total for Question 13 = 19 marks)

Question Number	Answer	Mark
2	**D Comparing to y=mx+c format with v as y and $\sqrt{T}$ as x**	**1**
	Incorrect Answers: A – this assumes T is proportional to $\sqrt{v}$ B – this assumes v is proportional to T C – this assumes $\frac{1}{T}$ is proportional to v	

8	**C - $\mu = \frac{1}{\text{gradient}}$**	**1**
	Incorrect Answers: A – incorrect use of $v = \sqrt{\frac{T}{\mu}}$ B – incorrect use of $v = \sqrt{\frac{T}{\mu}}$ D - incorrect use of $v = \sqrt{\frac{T}{\mu}}$	

(Total for Multiple Choice Questions = 8 marks)

Question Number	Acceptable answers	Additional guidance	Mark
6	D		1

Question Number	Acceptable Answer	Additional Guidance	Mark
3(a)	Any **TWO** from: • Should have used (a fiducial mark as) a reference point **(1)** • Should have timed from the equilibrium position of the bob **Or** Shouldn't time from the maximum displaced position of the bob **(1)** • Only timed one oscillation **Or** should have times more than one oscillation **(1)** • Should have allowed the pendulum to swing to and fro a few times before starting to time (as the first swing may be different from the others) **(1)**	Accept centre/vertical/undisplaced position for equilibrium position	**2**
3(b)	• Determination of gradient **(1)** • Re-arrangement of $T = 2\pi\sqrt{\frac{l}{g}}$ **(1)** • Algebra to show $T^2 = -\frac{4\pi^2}{g}d + \frac{4\pi^2}{g}h$ **(1)** • Gradient = $(-)\frac{4\pi^2}{g}$ **(1)** • g = 9.6 m s^{-2} [accept 9.5 → 9.7 m s^{-2}] **(1)**	$T^2 = \frac{4\pi^2}{g}l$ $T^2 = \frac{4\pi^2}{g}(h-d)$ $T^2 = -\frac{4\pi^2}{g}d + \frac{4\pi^2}{g}h$ Example of calculation $\text{gradient} = \frac{(12.1 - 9.2)\ \text{s}^2}{(0.00 - 0.70)\ \text{m}} = -4.1\ \text{s}^2\text{m}^{-1}$ $\therefore g = \frac{4\pi^2}{4.1\ \text{s}^2\text{m}^{-1}} = 9.6\ \text{m s}^{-2}$	**5**

(Total for Question 3 = 7 marks)

Question Number	Acceptable answers	Additional guidance	Mark
12(a)	• Use a pulley and set of masses/weights hung on string **(1)** • Tension = weight (of set of masses) **Or** $T=mg$ **(1)**		**2**
12(b)	• Calculate missing $f^2 = 9025$ **(1)** • Plot missing point **(1)** • Draw line of best fit **(1)**	Plot (35, 9025) or their calculated value of f^2	**3**
12(c)	• Determines the gradient **(1)** • Equates $v = f\lambda$ and $v = \sqrt{\frac{T}{\mu}}$ **(1)** • Uses $\lambda = 0.8$ (m) **(1)** • Mass per unit length μ = (6.0 to 6.2) x 10^{-3} (kg m^{-1}) **(1)** • Conclusion consistent with their value **(1)**	e.g. gradient= $\frac{(10200-0)}{(40-0)}$ =255 accept $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ $\mu = \frac{1}{255\text{Hz}^2\text{N}^{-1} \times 0.8^2\text{m}^2}$ =6.1 x 10^{-3} (kg m^{-1})	**5**

(Total for Question 12 = 10 marks)

<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th>Additional Guidance</th><th>Mark</th></tr>
<tr><td>9(a)</td><td>An explanation that makes reference to the following points:
• Shows expansion log $v = p \log B + \log k$ (1)
• Compares with $y = mx + c$ and identifies p as the gradient (1)</td><td></td><td>2</td></tr>
<tr><td>9(b)(i)</td><td>• Log values correct and to 3 SF (1)
<table>
<tr><th>Log (v /m s^{-1})</th><th>Log B</th></tr>
<tr><td>0.301</td><td>0.00</td></tr>
<tr><td>1.00</td><td>0.477</td></tr>
<tr><td>1.33</td><td>0.699</td></tr>
<tr><td>1.56</td><td>0.845</td></tr>
<tr><td>1.70</td><td>0.954</td></tr>
<tr><td>1.83</td><td>1.04</td></tr>
</table>
• Labels and unit (1)
• Scales (1)
• Plots (1)
• Line of best fit (1)</td><td>Allow ln v against ln B
<table>
<tr><th>ln (v /m s^{-1})</th><th>ln B</th></tr>
<tr><td>0.693</td><td>0.00</td></tr>
<tr><td>2.30</td><td>1.10</td></tr>
<tr><td>3.07</td><td>1.61</td></tr>
<tr><td>3.58</td><td>1.95</td></tr>
<tr><td>3.92</td><td>2.20</td></tr>
<tr><td>4.22</td><td>2.40</td></tr>
</table>
Check labels on graph axes (not table)
Don’t credit difficult scales (e.g. increments of 3, 4, 7)
Check 2 points furthest from the line (within half a square) Don’t check points on difficult scales</td><td>5</td></tr>
<tr><td>9(b)(ii)</td><td>• Gradient determined using large triangle - at least half the plotted length (1)
• p = 1.47 to 2/3 SF and no units (1)
• Obtains k = 2.00 m s^{-1} (1)</td><td>MP3 answer should round to 2; don’t penalise SF</td><td>3</td></tr>
</table>

(Total for Question 9 = 10 marks)

Question Number	Answers	Additional guidance	Mark
11(a)	• Use a micrometer **Or** vernier callipers **Or** digital callipers (1) • Measure diameter/width of ball at more than one orientation/position (1) • Calculate the mean of the diameter **and** divide by 2 (1)		3
(b)i	• Use of $V = \frac{4}{3}\pi r^3$ • Use of $\rho = \frac{m}{V}$ **and** $W = mg$ (1) (1) • $W = 4.1 \times 10^{-2}$ (N) (1)	Example of Calculation $WW = 8.0 \times 10^3\ \text{kg m}^{-3} \times \frac{4}{3}\pi(0.005\ \text{m})^3 \times 9.81\ \text{m s}^{-2}$ $W = 4.11 \times 10^{-2}$ N	3
(b)ii	• Use of $F = 6\pi r\eta v$ (1) • $v = 0.24\ \text{m s}^{-1}$ (1)	Example of Calculation $4.1 \times 10^{-2}\ \text{N} = 6\pi \times 0.005\ \text{m} \times 1.78\ \text{N s m}^{-2} \times v$ $v = \frac{4.1 \times 10^{-2}\ \text{N}}{6\pi \times 0.005\ \text{m} \times 1.78\ \text{N s m}^{-2}}$ $v = 0.24\ \text{m s}^{-1}$	2
(c)	• Ensure the velocity is low **Or** use small (radius) spheres **Or** use a wide cylinder (1) • To prevent turbulence **Or** to ensure laminar flow (1)		2

(Total for Question 11 = 10 marks)

9(a)

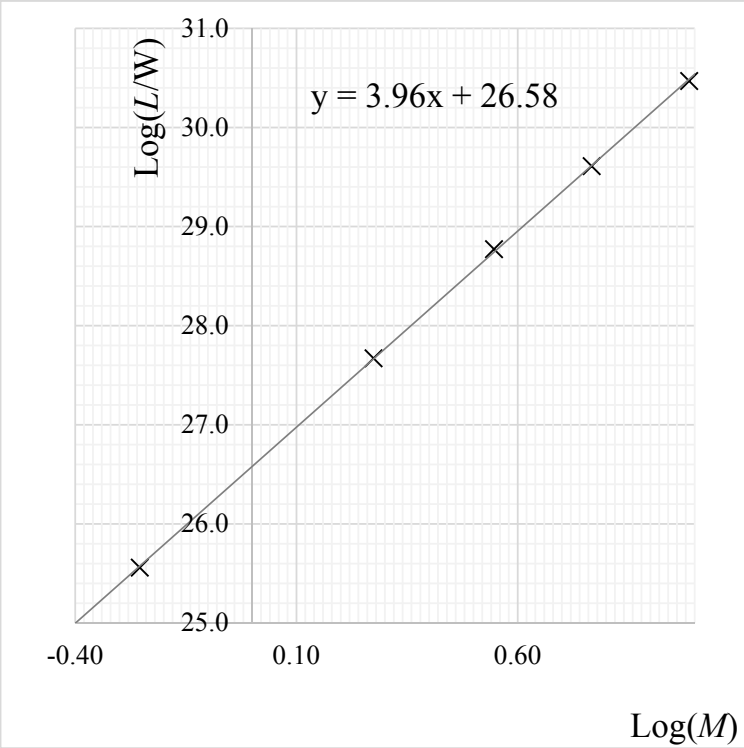
An explanation that makes reference to the following points:

- Shows expansion $\log L = p\log(M) + \log(L_{Sun})$ **(1)**
- Compares with y = mx+ c **(1)**

2

9(b)(i)

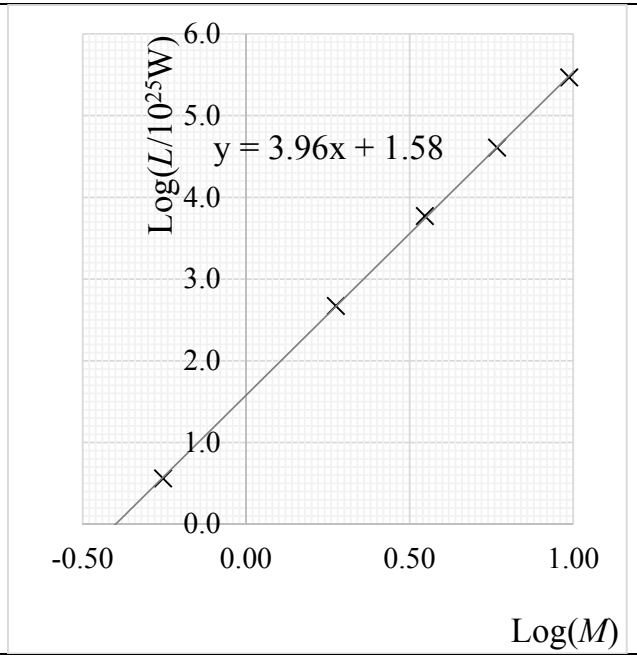
- Log values correct and consistent to 3/4 SF **(1)**
- Labels and unit **(1)**
- Scales **(1)**
- Plots **(1)**
- Line of best fit **(1)**



Log (L /W)	Log (L /10^{25} W)	Log (M /M_{Sun})
25.56	0.560	−0.254
27.67	2.67	0.274
28.77	3.77	0.547
29.61	4.61	0.767
30.47	5.47	0.988

Ln (L /W)	Ln (L /10^{25} W)	Ln (M /M_{Sun})
58.85	1.29	−0.585
63.72	6.15	0.631
66.25	8.69	1.26
68.18	10.6	1.77
70.16	12.6	2.27

5

			
9(b)(ii)	• Determines gradient using large triangle $-\Delta x \geq 0.6$ **(1)** • gradient = (3.9→ 4.0) to 2/3 SF and no units **(1)** • reads intercept on y-axis and takes antilog to give a value for L_{Sun} **(1)** • States $L = 4 \times 10^{26} M^4$ **(1)**	$L_{Sun} = 4 \times 10^{26}$ W (accept any value that rounds to 4)	**4**

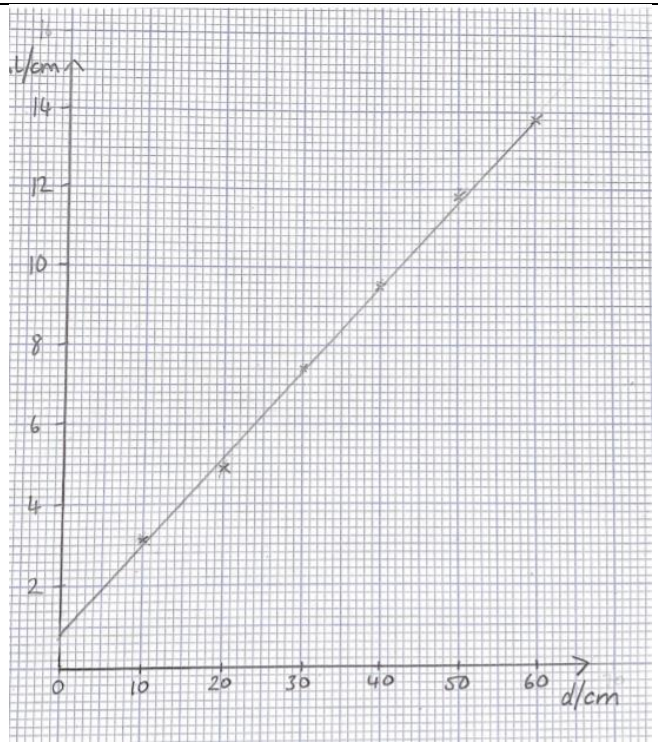
(Total for Question 9 = 11 marks)

Question Number	Acceptable answers		Additional guidance	Mark
16(a)	• Check that the top of the spring is aligned with zero on the ruler	(1)		Max 2
	• Move the rule close to the spring **Or** Ensure that rule is parallel to the spring **Or** Ensure the metre rule is vertical using a set square	(1)		
	• View (the rule) perpendicularly **Or** Use a set square to take the measurement from the rule	(1)		

16(b)(i)

- Processing of data to calculate extension **(1)**
- Axes with labels & units **(1)**
- Scales **(1)**
- Plots **(1)**
- Line of best fit **(1)**

d / cm	l / cm	Δl / cm
10.0	6.6	3.1
20.0	8.4	4.9
30.0	10.9	7.4
40.0	13.0	9.5
50.0	15.3	11.8
60.0	17.3	13.8



MP3: scales only in 1,2,5 and must cover at least half of paper

MP4: a 1 mm square tolerance, check all points

5

16(b)(ii)

- Determine gradient using a large triangle **(1)**
- Use of $gradient = \frac{W}{kD}$ **(1)**
- k in range 25.6 – 27.2 **(1)**
- 3 significant figures and unit given **(1)**

Example Calculation

$$gradient = \frac{0.138 - 0.008}{0.600 - 0.000}$$

Gradient = 0.217

$$0.217 = \frac{5.0\ \text{N}}{k \times 0.875\ \text{m}}$$

$k = 26.4\ \text{N m}^{-1}$

4

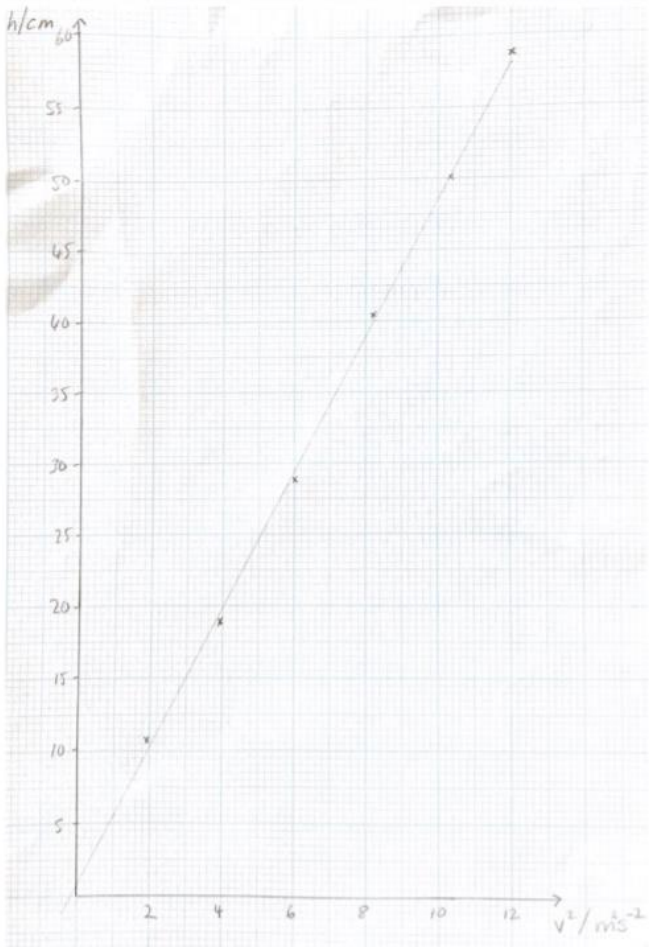
(Total for Question 16 = 11 marks)

Question Number	Acceptable answers	Additional guidance	Mark
16(a)	• Use of a metre rule **(1)** • Use of a set square to ensure the rule is vertical **Or** Use of plumbline to ensure that the rule is vertical **(1)**	Allow use of a spirit level for MP2	**2**
16(b)(i)	An explanation that makes reference to the following points: • Comparison of $h = \frac{v^2}{2g}$ with $y = mx + c$ **(1)** • Gradient = $\frac{1}{2g}$ which is constant **(1)**		**2**

16(b)(ii)

- Values of v^2 given to 3 s.f. **(1)**
- Axes with labels & units **(1)**
- Scales **(1)**
- Plots **(1)**
- Line of best fit **(1)**

h / cm	v^2/ m^2 s^{-2}
10.8	1.90
18.9	3.92
28.7	6.00
40.3	8.18
49.8	10.37
58.7	11.97



MP1 allow 4 s.f. for final two values in table
MP3: scales only in 1,2, or 5 and must cover at least half of paper

5

16(b)(iii)	• Use of large triangle **(1)** • Use of gradient = $\frac{1}{2g}$ **(1)** • g in range 10.0 – 10.9 (m s^{-2}) and relevant comment **(1)**	Example of calculation Gradient = (0.580 – 0.005) / 12.0 = 0.0479 g = 1 / (2 × 0.0479) = 10.4 m s^{-2}	**3**

(Total for Question 16 = 12 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
11(a)	• Data not recorded to the same sf/dp **(1)** • Positions of mass holder not recorded **(1)**		**2**
11(b)	• Attempt to calculate gradient **(1)** • k = (24.0 →25.0) N m^{-1} **(1)**	Accept k = (0.24→ 0.25) N cm^{-1} Example of calculation: gradient= $\frac{(1.6\text{-}0)\text{ N}}{(6.5\text{-}0)\times10^{-2}\text{m}}$ =24.6 N m^{-1}	**2**
11(c)	• new spring constant = 11 N m^{-1} **(1)** • Use of $T = 2\pi\sqrt{\frac{m}{k}}$ **(1)** • Use of $f = 1/T$ **(1)** • f = 1.5 Hz **(1)**	Example of calculation: k = 22/2 = 11 N m^{-1} $T = 2\pi\sqrt{\frac{0.12\,\text{kg}}{11\,\text{N m}^{-1}}} = 0.66\,\text{s}$ f = 1/0.66 s = 1.5 Hz	**4**

***11(d)**

This question assesses a student's ability to show a coherent and logical structured answer with linkage and fully-sustained reasoning.
Marks are awarded for indicative content and for how the answer is structured and shows lines of reasoning.
The following table shows how the marks should be awarded for indicative content.

Number of indicative points seen in answer	Number of marks awarded for indicative points
6	4
5-4	3
3-2	2
1	1
0	0

Indicative content:

- As magnet A moves, its coil experiences a change of magnetic flux (linkage)
- The change in magnetic flux linkage induces an emf in the coil
- The (induced) emf causes a current in both coils
- The current in the second coil causes a force to act on magnet B, driving magnet B into oscillation
- Because both mass-spring systems have the same period/frequency
- Resonance occurs (and magnet B oscillates with increasing amplitude)

The following table shows how the marks should be awarded for structure and lines of reasoning

	Number of marks awarded for structure and lines of reasoning
Answer shows a coherent and logical structure with linkage and fully sustained lines of reasoning demonstrated throughout	2
Answer is partially structured with some linkages and lines of reasoning	1
Answer has no linkage between points and is unstructured	0

Linkage Marks

IC points 1 – 4
Three of these points could score one linkage mark

IC points 5 & 6 could score one linkage mark

.

6

(Total for Question 11 = 14 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark

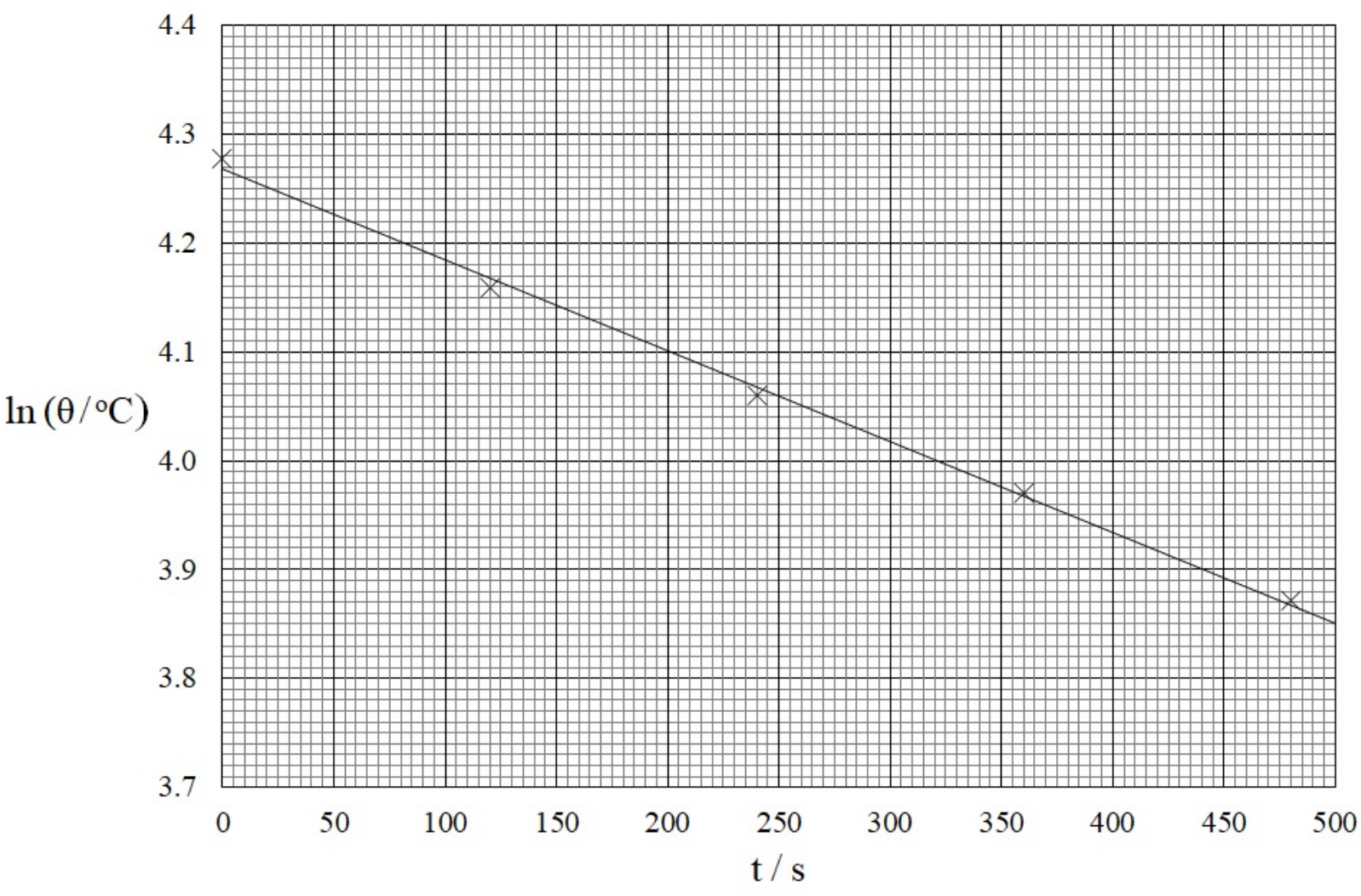
<table>
<tr><th>Question Number</th><th>Acceptable Answer</th><th></th><th>Additional Guidance</th><th></th></tr>
<tr><td>8(a)</td><td>An explanation that makes reference to the following points:
• Shows expansion $\ln \Delta\theta = \ln \Delta\theta_o - bt$
• Compares with $y = mx + c$ and states that the gradient is b (which is constant)</td><td>(1)

(1)</td><td></td><td>2</td></tr>
<tr><td>8(b)(i)</td><td>• ln values correct (at least 2 dec.places)
• Labels and unit
• Scales
• Plots
• Line of best fit</td><td>(1)
(1)
(1)
(1)
(1)</td><td><table><tr><th>Δθ / °C</th><th>ln (Δθ / °C)</th></tr><tr><td>72</td><td>4.277</td></tr><tr><td>64</td><td>4.159</td></tr><tr><td>58</td><td>4.060</td></tr><tr><td>53</td><td>3.970</td></tr><tr><td>48</td><td>3.871</td></tr></table></td><td>5</td></tr>
<tr><td>8(b)(ii)</td><td>• Determines gradient using large triangle
• $b = 8 \times 10^{-4} \rightarrow 9 \times 10^{-4}$ (2 or 3 sf)
• Units s^{-1}</td><td>(1)
(1)
(1)</td><td><u>Example of calculation:</u>

$m = \frac{4.27 - 3.85}{(0 - 500)\ s} = 8.4 \times 10^{-4}\ s^{-1}$</td><td>3</td></tr>
</table>

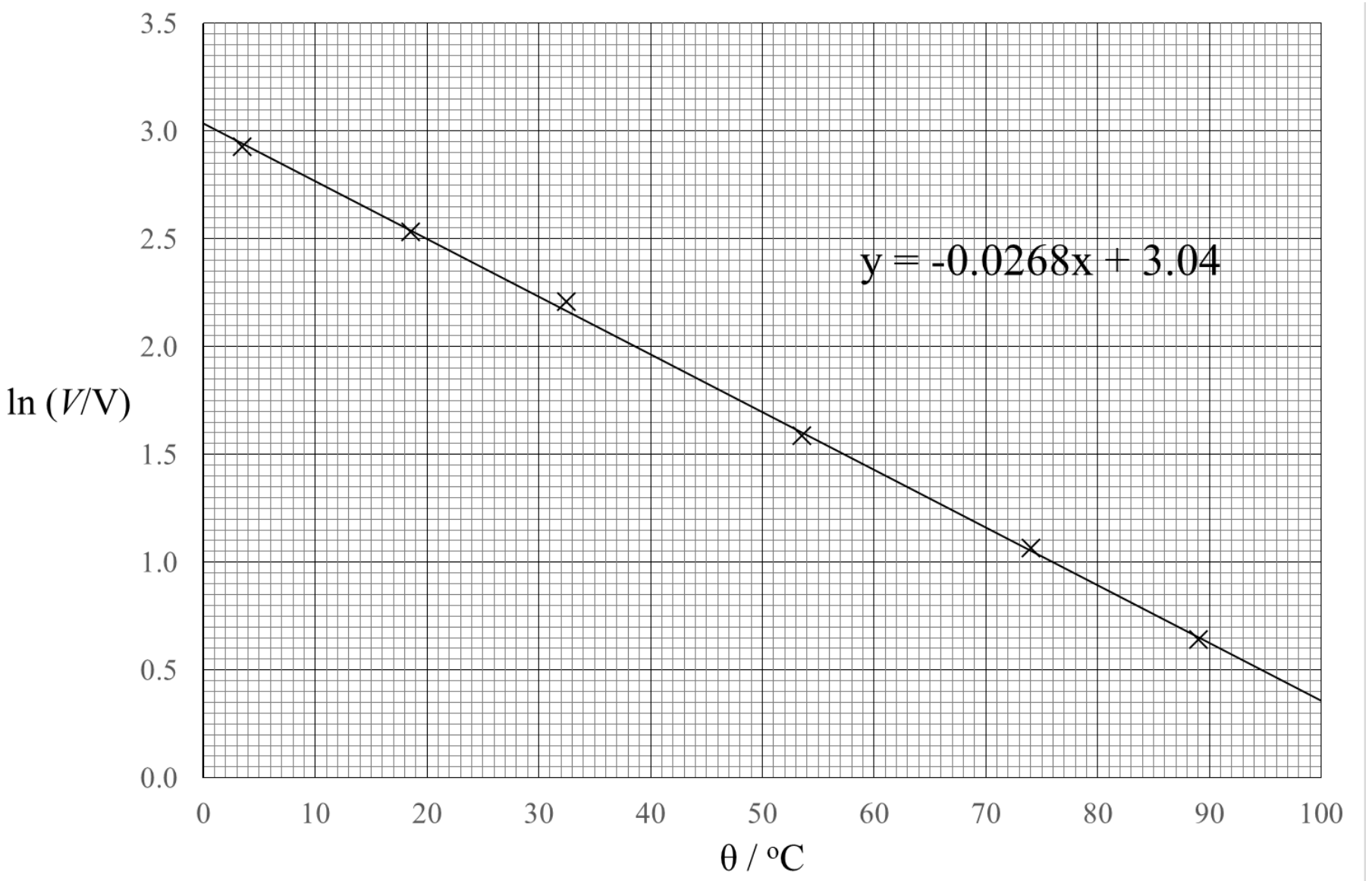
8(c)	**MAX 3 from** • Dataloggers are useful when data changes over a very short (or very long) time scale • Dataloggers are useful when a number of quantities are being measured simultaneously • A comment on the time between temperature readings in this experiment. • It takes longer for the liquid in glass thermometer to respond to temperature changes than the temperature sensor • There may be parallax error in reading from the liquid in glass thermometer • Conclusion consistent with discussion of suitability of using a data logger	**(1)** **(1)** **(1)** **(1)** **(1)** **(1)**		**4**

(Total for Question 8 = 14 marks


4.4
4.3
4.2
4.1
4.0
3.9
3.8
3.7
ln (θ / °C)
0
50
100
150
200
250
300
350
400
450
500
t / s

Question Number	Acceptable Answer		Additional Guidance	
11(a)	An explanation that makes reference to the following points: • The number of (free) charge carriers (per unit volume) in the thermistor decreased • (Hence) the resistance of the thermistor increased • And a larger fraction of supply p.d. is across the thermistor	**(1)** **(1)** **(1)**	MP1: Electrons okay for charge carriers MP3: Current in circuit decreases, so p.d. across fixed resistor decreases, therefore p.d. across thermistor increases	**3**
11(b)(i)	An explanation that makes reference to the following points: • Shows expansion $\ln(V) = \ln(V_0) - b\theta$ • Compares with $y = mx + c$ and shows that m is $(-)b$	**(1)** **(1)**		**2**
11(b)(ii)	• Ln values correct and to 2 or 3 decimal places • Labels and unit • Scales • Plots • Line of best fit	**(1)** **(1)** **(1)** **(1)** **(1)**	θ /°C | V /V | ln (V/V) | ln (V/V) 89.0 | 1.9 | 0.642 | 0.64 74.0 | 2.9 | 1.065 | 1.06 53.5 | 4.9 | 1.589 | 1.59 32.5 | 9.1 | 2.208 | 2.21 18.5 | 12.6 | 2.534 | 2.53 3.5 | 18.7 | 2.929 | 2.93	**5**
11(b)(iii)	• Gradient determined using large triangle • b in range (0.026 → 0.028) °C^{-1} to 2 or 3 sf with unit • Inverse ln of intercept determined • V_0 in range (19 → 22) V	**(1)** **(1)** **(1)** **(1)**	MP2: unit can be K^{-1} Example of calculation: $\text{gradient} = \frac{(3.04 - 0.35)}{(0 - 100)\ ^{o}\text{C}} = -0.027\ \ ^{o}\text{C}^{-1}$ $V_0 = e^{3.0}\ \text{V} = 20.1\ \text{V}$	**4**

(Total for Question 11 = 14 marks)

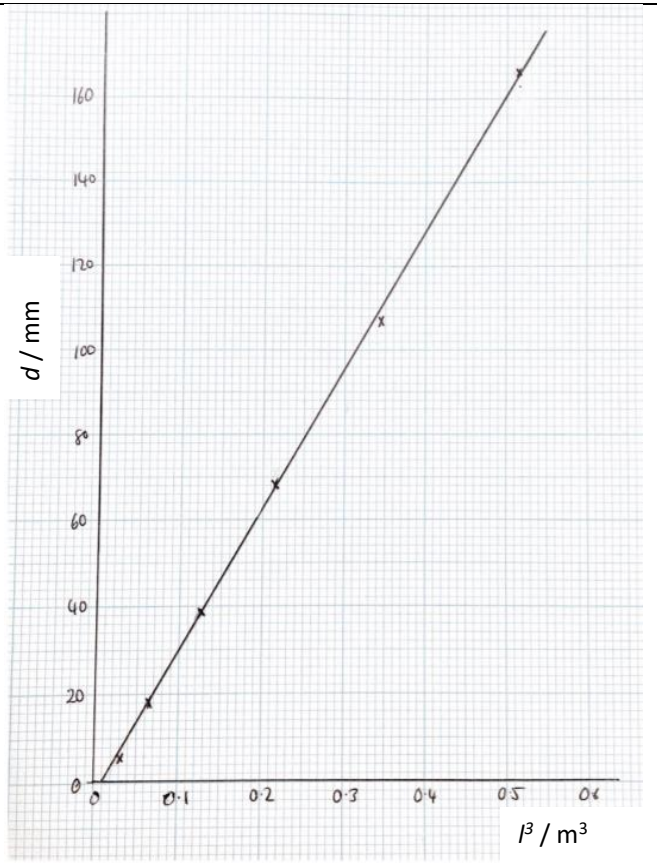

y = -0.0268x + 3.04
ln (V/V)
θ / °C
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
60
70
80
90
100

Question Number	Acceptable answers	Additional guidance	Mark
17(a)	• Ensure the metre rule is vertical using a set square placed in contact with the floor. **(1)** • Use set square held against metre rule to take the readings on the metre rule **(1)**	A labelled diagram can score full marks Accept references to reading at eye level for MP2.	**2**
17(b)(i)	• Use of half range **Or** Use of maximum deviation from the mean **(1)** • 0.4 (%) **(1)**	<u>Example of Calculation.</u> ½ range = (6.29 mm - 6.24 mm) / 2 = 0.025 mm %U = (0.025 mm / 6.26 mm) x 100 %U = 0.40 %	**2**

17(b)(ii)

- Correct values for l^3 to 3 sf **(1)**
- Axes with labels & units **(1)**
- Scales **(1)**
- Plots **(1)**
- Line of best fit **(1)**

l/m	*d/mm*	l^3 / m^3
0.300	6	0.027(0)
0.400	18	0.064(0)
0.500	39	0.125
0.600	68	0.216
0.700	107	0.343
0.800	166	0.512



MP1: accept 2 or 3 sf's in table for first 2 values
MP3: scales only in 1,2,5 and must cover at least half of paper

MP4: a 1 mm square tolerance, check all points

5

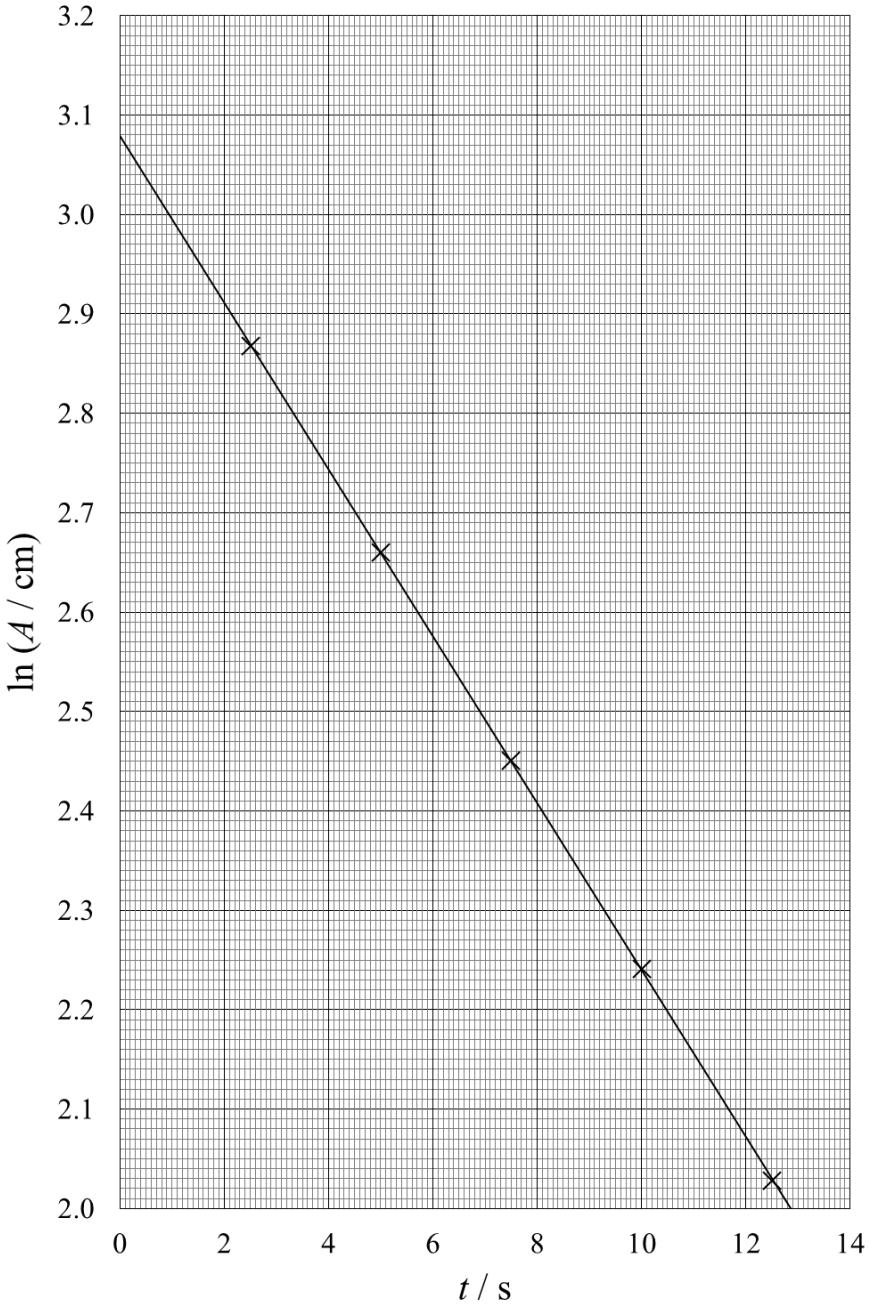
17(b)(iii)	• Determine gradient **(1)** • Using a large triangle **(1)** • Use of gradient $= \frac{4W}{Ebt^3}$ **(1)** • $E = 9.2 \times 10^9$ (Pa) (in range $8.9 – 9.3 \times 10^9$ (Pa)) **(1)** • Identifies wood consistent with their value for E **(1)**	Example Calculation. $gradient = \frac{(160 \times 10^{-3}) - 0}{0.50 - 0.01}$ Gradient = 0.327 $0.327 = \frac{4 \times 5.6\ (\text{N})}{E\ x\ 0.0302\ (\text{m}) \times (6.26x10^{-3}\ (\text{m}))^3}$ $E = 9.2 \times 10^9$ Pa	**5**

(Total for Question 17 = 14 marks)

Question Number	Acceptable Answer	Additional Guidance	Mark
10(a)(i)	• Use of $T = 2\pi\sqrt{\frac{\ell}{g}}$ **(1)** • ℓ = 1.55 m **(1)**	Example of calculation $\ell = \frac{(2.50\text{ s})^2 \times 9.81\text{ m s}^{-2}}{4\pi^2} = 1.55\text{ m}$	**2**
10(a)(ii)	An explanation that makes reference to the following points: • Resistive forces act on the pendulum **Or** The oscillation is damped **(1)** • Work is done against the resistive/damping forces **(1)** • So the energy **and** amplitude of the oscillation/pendulum decreases **(1)**	Accept "energy is transferred from the system" for "energy decreases"	**3**
10(b)(i)	An explanation that makes reference to the following points: • Shows expansion $\ln(A) = -\left(\frac{k}{T}\right)t + \ln A_0$ **(1)** • Compares with $y = mx + c$ and states/indicates that gradient is $-\frac{k}{T}$ (which is a constant) **(1)** **OR** • Shows expansion $\ln(A) = \ln A_0 - \left(\frac{k}{T}\right)t$ **(1)** • Compares with $y = c + mx$ and states/indicates that gradient is $-\frac{k}{T}$ (which is a constant) **(1)**		**2**

10(b)(ii)	• Ln values correct and all to 2 decimal places **Or** Ln values correct and all to 3 decimal places **(1)** • Labels and unit **(1)** • Scales **(1)** • Plots **(1)** • Line of best fit **(1)**	<table><tr><th>t / s</th><th>A / cm</th><th>ln (A/cm)</th><th>ln (A/cm)</th></tr><tr><td>2.5</td><td>17.6</td><td>2.868</td><td>2.87</td></tr><tr><td>5.0</td><td>14.3</td><td>2.660</td><td>2.66</td></tr><tr><td>7.5</td><td>11.6</td><td>2.451</td><td>2.45</td></tr><tr><td>10.0</td><td>9.4</td><td>2.241</td><td>2.24</td></tr><tr><td>12.5</td><td>7.6</td><td>2.028</td><td>2.03</td></tr></table>	**5**
10(b)(iii)	• Inverse ln of intercept determined **(1)** • A_0 = 22 cm to 2 or 3 sf [Allow answers that round to 21 cm or 22 cm] **(1)** • Gradient determined using large triangle **(1)** • k = 0.21 to 2 or 3 sf [Answers must round to 0.21] **(1)**	Only withhold mark for incorrect s.f. once in this part Example of calculation $\text{grad} = \frac{(3.08 - 2.00)}{(0 - 12.9)\text{ s}} = -0.0837\text{ s}^{-1}$ $k = 0.0837\text{ s}^{-1} \times 2.50\text{ s} = 0.209$ $\ln A_0 = 3.08$ $A_0 = \text{e}^{3.08} = 21.8\text{ cm}$	**4**

(Total for Question 10 = 16 marks)

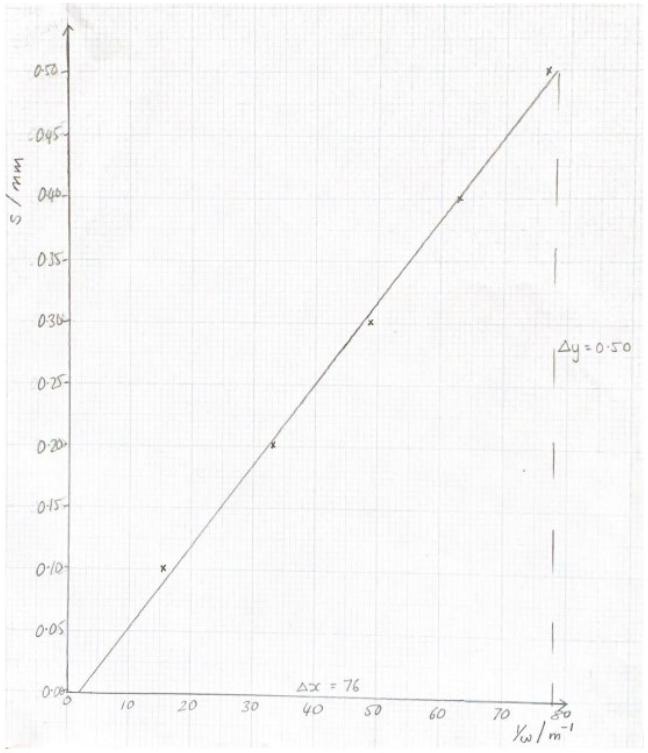

3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
ln (A / cm)
0
2
4
6
8
10
12
14
t / s

Question Number	Acceptable Answer	Additional Guidance	Mark
16(a)	An explanation that makes reference to the following points: • Measure across n fringe separations and divide by n **(1)** **Or** Accept increase D (so w is larger) • The uncertainty stays the same but the measurement is larger (so the percentage uncertainty in w is decreased) **(1)**		**2**

16(b)(i)

- Values of 1/*w* given to 3 sf **(1)**
- Axes with labels & units **(1)**
- Scales **(1)**
- Plots **(1)**
- Line of best fit **(1)**

s / mm	*w* / m	1/*w* / m^{-1}
0.10	0.0643	15.6
0.20	0.0301	33.2
0.30	0.0204	49.0
0.40	0.0159	62.9
0.50	0.0131	76.3



MP3 scales only in 1,2 and 5, and must cover at least half the grid

MP4 tolerance of ½ graph square, check all points.

5

16(b)(ii)	• Use of large triangle **(1)** • Use of gradient = λD **(1)** • λ in range 6.9 – 7.7 × 10^{-7} m to 2 or 3 significant figures **(1)**	<u>Example of calculation</u> Gradient = (0.50 − 0) × 10^{-3} / (78 – 2) = 6.6 × 10^{-6} λ = 6.6 × 10^{-6} / 9.00 = 7.3 × 10^{-7} m	**3**

16(c)(i)	• Use of ½ range **Or** Use of furthest from mean **(1)** • $\%U_f = 9\%$ **(1)**	Example of calculation $\%U_f = ½(24 - 20) \times 100 / 22 = 9\%$	**2**

16(c)(ii)	**EITHER** • Use of $s = \frac{\lambda D}{w}$ **(1)** • Percentage uncertainty calculated for D **(1)** • Percentage uncertainties for D, s and w added (ecf from (c)(i)) **(1)** • Upper limit of $\lambda = 5.52 \times 10^{-7}$ m which is greater than 520 nm so student's results are consistent with value on label **Or** Comparison of calculated value of relevant limit of wavelength with 520 nm and valid conclusion **(1)** **OR** • Maximum or minimum value calculated for s or w **(1)** • Calculation of upper or lower limit using maximum/minimum values **(1)** • Calculation of both limits using maximum and minimum values **(1)** • Upper limit of $\lambda = 5.55 \times 10^{-7}$ m which is greater than 520 nm and lower limit of $\lambda = 4.26 \times 10^{-7}$ m which is less than 520 nm so student's results are consistent with value on label **(1)**	Example of calculation $\lambda = (22 \times 10^{-3}\text{ m} \times 0.20 \times 10^{-3}\text{ m}) / 9.00 = 4.89 \times 10^{-7}$ m $\%U_D = 0.01 \times 100 / 9.00 = 0.1\ \%$ $\%U_\lambda = \%U_D + \%U_s + \%U_w$ $\%U_\lambda = 9\% + 0.1\% + 4\% = 13\%$ $U_\lambda = 0.13 \times 4.89 \times 10^{-7}\text{ m} = 6.36 \times 10^{-8}$ m Upper limit of $\lambda = 4.89 \times 10^{-7}\text{ m} + 6.36 \times 10^{-8}$ m Upper limit of $\lambda = 5.52 \times 10^{-7}$ m MP3 – accept ecf from c(i) Example of Calculation $s_{max} = 0.20 \times 10^{-3}\text{ m} \times 1.04 = 2.08 \times 10^{-4}$ m $w_{max} = 22 \times 10^{-3}\text{ m} \times 1.09 = 0.024$ m $\lambda_{max} = (0.024\text{ m} \times 2.08 \times 10^{-4}\text{ m})/(9.00-0.01)$ m $\lambda_{max} = 5.55 \times 10^{-7}$m $s_{min} = 0.20 \times 10^{-3}\text{ m} \times 0.96 = 1.92 \times 10^{-4}$ m $w_{min} = 22 \times 10^{-3}\text{ m} \times 0.91 = 0.020$ m $\lambda_{min} = (0.020\text{ m} \times 1.92 \times 10^{-4}\text{ m})/(9.00+0.01)$ m $\lambda_{min} = 4.26 \times 10^{-7}$m MP3 – accept ecf from c(i)	**4**

(Total for Question 16 = 16 marks)