Physics Summer Essay Project

- Agreed title and topic of study in an area of your interest before end of term
- Can choose a topic which interests you/relevant to your university courses with a physics ‘angle’
- Minimum 1500 words
- Independent/original work
- Referencing – Harvard style
- Submission – 2nd week back September 26

Previous Titles and Subject Matter

- How have planes become more sustainable over time?
- Behind the pinnacle of motorsport in F1
- What is the future of energy?
- How do supernovas affect computers
- Will quantum computers ever become commercialised
- The logistics of warp drive and feasibility
- The many worlds of interpretation
- how mechanical engineering can help reduce climate change
- Quantum immortality
- How n-body simulations have explained the universe and its interactions

- How to make An Invisibility Cloak: The study of Photonic Crystals
- The problems of domesticating quantum computing
- How time dilation works
- Theories about the future of the universe
- Utilisation of Snell’s law and its applicatior
- Is light a particle or wave?
- Is time travel possible?
- The Duality Of Black holes and White holes

Summer 26 Physics Practice Booklet

Name: ______________________

Class: ______________________

Date: ______________________

Time: **6hrs**

Marks: **199 marks**

Comments:

Q1.

(a) Determine whether the following reaction is a possible decay for the neutral pion π^0.

$$\pi^0 \rightarrow e^- + \mu^+ + \bar{\nu}_e$$

(2)

(b) State the **two** possible quark configurations of a π^0.

1.

2.

(1)

(c) A student suggests that the kaon K^0 and the anti-kaon $\overline{K^0}$ are the same particle.

Discuss whether this suggestion is correct.

(2)

(d) The nucleus is held together by a force. It was predicted that a particle exists that is responsible for this force. The particle itself must experience this force.

The particle would have a rest energy between that of an electron and half that of a nucleon.

Discuss whether a kaon, a muon and a pion **each** have the properties of the predicted particle.

Information about these three particles is in the Data and Formulae Booklet.

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(4)
(Total 9 marks)

Q2.

Two stable isotopes of helium are ${}^{4}_{2}\mathrm{He}$ and ${}^{3}_{2}\mathrm{He}$.

(a) An atom of ${}^{4}_{2}\mathrm{He}$ is produced in a rock that contains uranium. It is produced following the radioactive decay of a ${}^{238}_{92}\mathrm{U}$ atom. The decay also creates an atom of thorium (Th).

Write an equation for the decay of ${}^{238}_{92}\mathrm{U}$.

${}^{238}_{92}\mathrm{U} \rightarrow$

(2)

(b) A $^{3}_{2}\mathrm{He}$ nucleus can be produced by the decay of a tritium nucleus $^{3}_{1}\mathrm{H}$.

State and explain which exchange particle is responsible for this decay.

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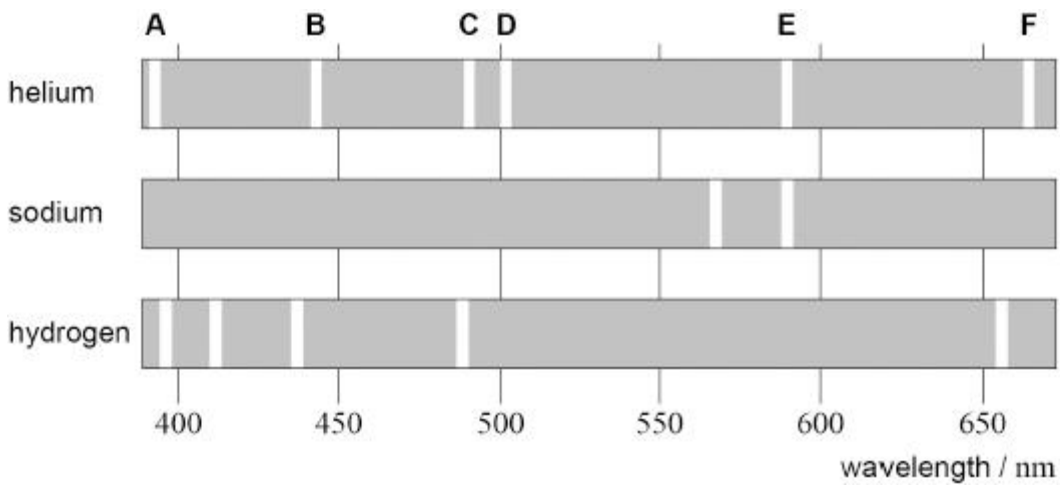
(2)

Helium was discovered by analysing the light in the **absorption** spectrum of the Sun.

The figure below shows the positions of the brightest lines, labelled **A** to **F**, in the **emission** spectrum of helium. The brightest lines in the emission spectra of sodium and hydrogen are also shown.



(c) Before helium was identified, some scientists suggested that the lines of the helium spectrum seen in the absorption spectrum of the Sun were due to the presence of sodium and hydrogen.

Discuss, with reference to the lines **A** to **F** in the figure above, the evidence for and against this suggestion.

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(2)

(d) Calculate, in eV, the change in energy level responsible for the spectral line labelled **E** in the diagram above.

change in energy level = ________________ eV

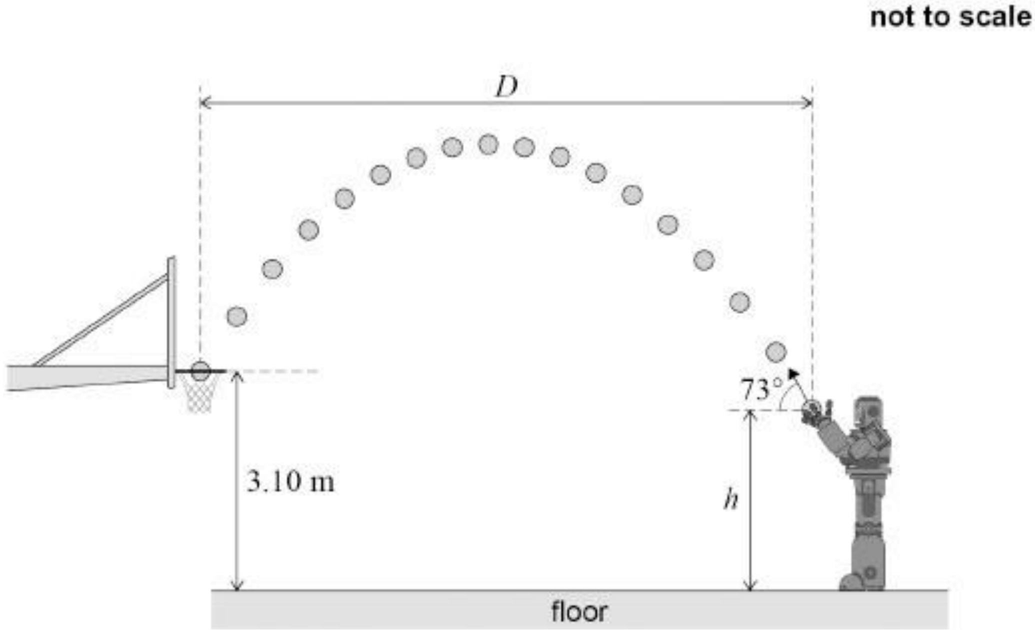
(3)

(e) Explain, with reference to the processes within an atom, the difference between an emission spectrum and an absorption spectrum.

(3)
(Total 12 marks)

Q3.

The figure below shows a series of time-lapse images of a basketball thrown by a robot. Images are taken at constant time intervals.



The robot throws the ball from a height h above the floor and at an angle of 73° to the horizontal.

The vertical component of the initial velocity of the ball is 8.7 $\mathrm{m\ s^{-1}}$.

The horizontal distance between the first image and the last image is D.

The time of flight for distance D is 1.7 s.

Assume that air resistance is negligible.

(a) Determine D.

D = ____________________________ m

(2)

(b) The vertical displacement of the ball from the floor in the last image is 3.10 m.

Determine h.

h = ____________________ m

(3)

(c) The ball is again thrown by the robot.
The initial speed of the ball is the same as in the figure above.
The angle for this throw is less than 73°.

Another set of images is taken as the ball moves through the same horizontal distance D.
The constant time interval between each image is unchanged.

Deduce whether the number of images of the ball is different from the number in the figure above.

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(2)

(d) When air resistance is significant, the magnitude of the vertical component a_v of the acceleration of the ball varies throughout the flight.

Discuss how air resistance affects a_v when the vertical displacement of the ball is:

- increasing
- decreasing.

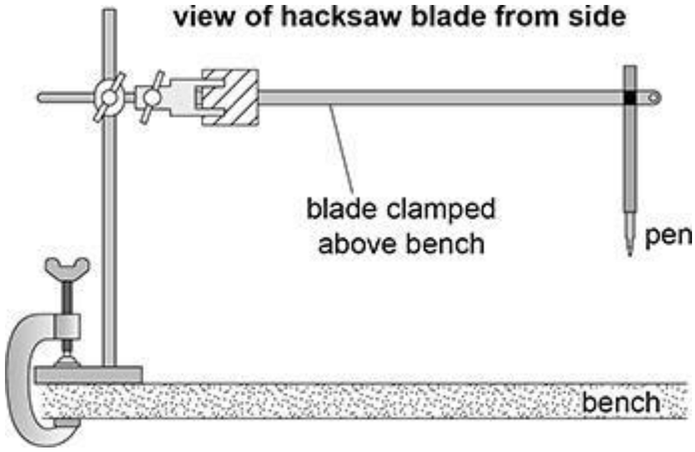
(3)

(Total 10 marks)

Q4.

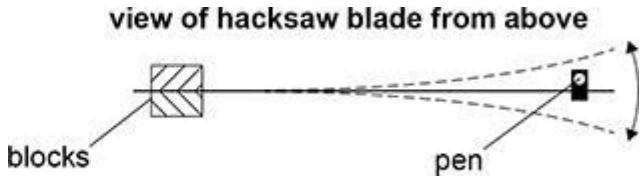
A hacksaw blade is a thin flexible strip of metal.
Figure 1 shows a blade clamped between two blocks above a horizontal bench. A pen is attached to the free end of the blade.

Figure 1



The free end of the blade is displaced and released.
The blade oscillates in a horizontal plane as shown in **Figure 2**.

Figure 2



The time for each oscillation is T.

(a) The table below shows repeated measurements of $60T$.

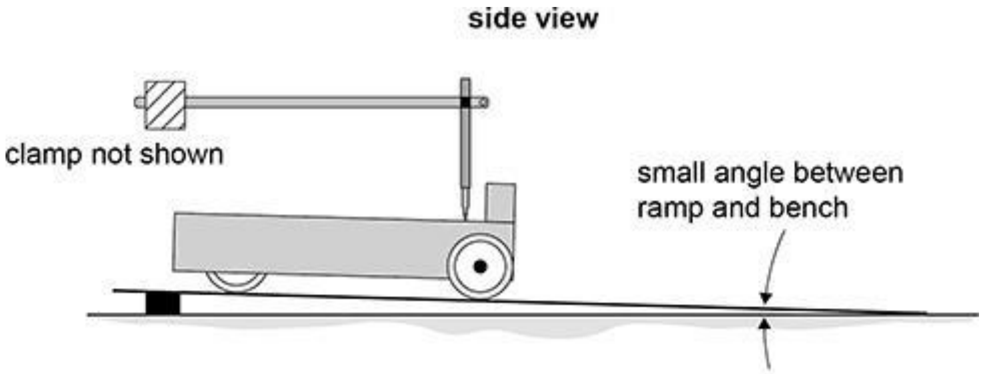
Measurements of $60T$ / s			
25.20	25.05	24.97	25.10

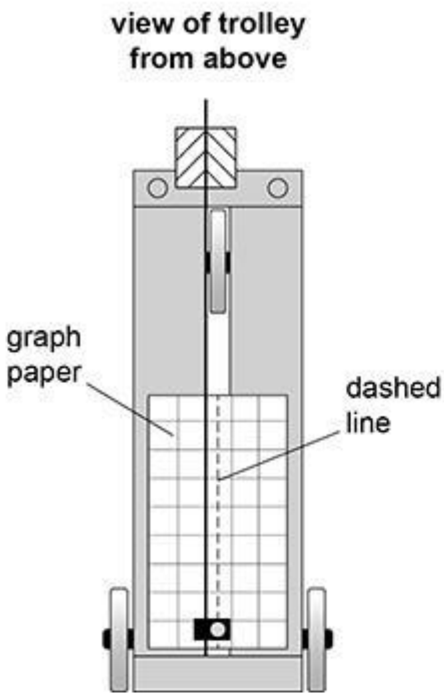
Show that T is about 0.42 s.

(1)

Figure 3 shows a trolley placed on a ramp that is inclined at a small angle to the bench.
A piece of graph paper is fixed to the upper surface of the trolley.
The blade and pen are positioned so that the tip of the pen rests on the graph paper.
The dashed line shows the rest position of the pen.

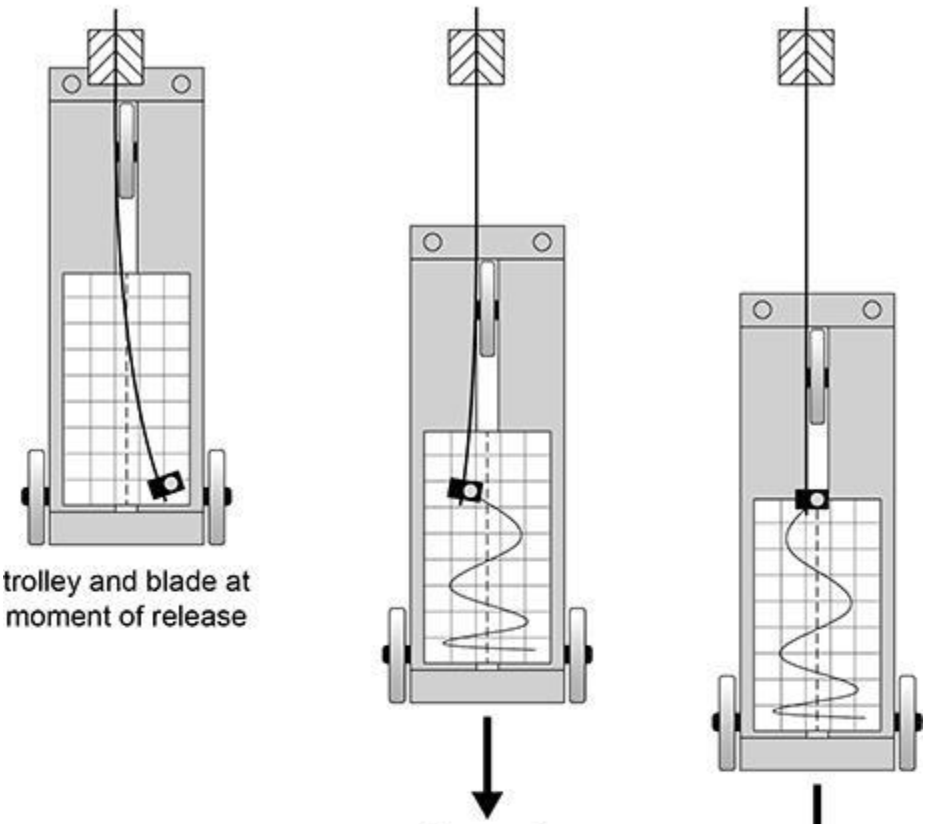
Figure 3





The free end of the blade is displaced as shown in **Figure 4a**.
The blade and the trolley are then both released at the same moment.
The blade oscillates horizontally.
The pen remains in contact with the graph paper as the trolley moves.
Figures 4b and **4c** show the trolley as it moves down the ramp with uniform acceleration.

Figure 4a Figure 4b Figure 4c



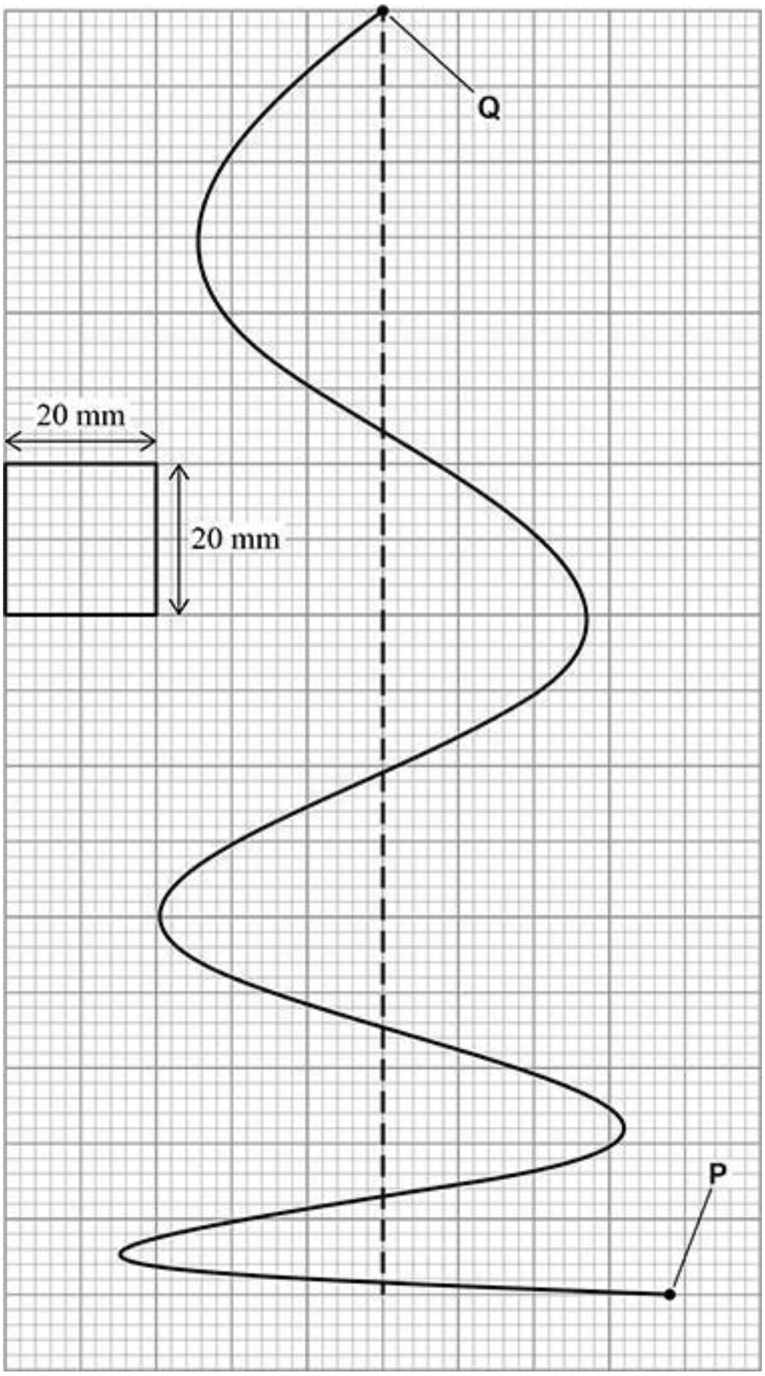
trolley and blade at moment of release

trolley moving down ramp

trolley moving down ramp

Figure 5 shows the graph paper.
Points **P** and **Q** mark the start and end of the continuous line drawn by the pen after the trolley is released.

Figure 5



T_{PQ} is the time for the pen to draw the line from **P** to **Q**.
s is the displacement of the trolley during T_{PQ}.

(b) Determine T_{PQ}.
Assume that the time for each full oscillation of the blade is 0.42 s.

T_{PQ} = ____________________ s

(2)

(c) Determine s.
The scale of the graph paper is shown on **Figure 5**.

s = ____________________ m

(1)

(d) Determine the acceleration a of the trolley.

a = ____________________ m s^{-2}

(2)

(e) A teacher suggests that the absolute uncertainty in s is ±2 mm.

Explain why this is a valid suggestion.

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(2)

(f) The percentage uncertainty in T_{PQ} is 0.46%.

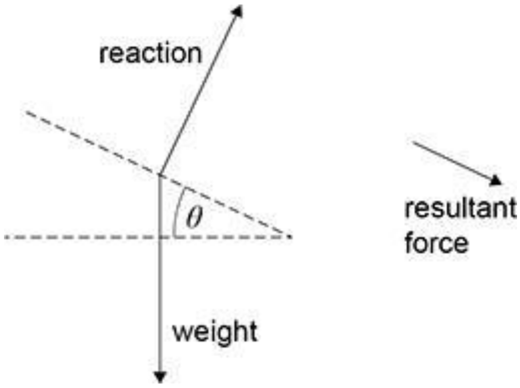
Determine the percentage uncertainty in your result for a.

percentage uncertainty = ____________________ %

(2)

(g) **Figure 6** is a diagram drawn by a student to explain why the trolley accelerates. The diagram is incomplete because the student has ignored the friction forces involved.

Figure 6



Using **Figure 6** it can be shown that:

$$g = \frac{a}{\sin\theta}$$

where a is the acceleration of the trolley.

The student determines g using this equation.

State and explain how the student's value of g compares with 9.81 $\mathrm{m\ s^{-2}}$.

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(2)

(Total 12 marks)

Q5.

Figure 1 shows a robotic helicopter that is used on Mars. The helicopter is powered by a battery. Before each flight, the battery is charged by a solar panel.

Figure 1

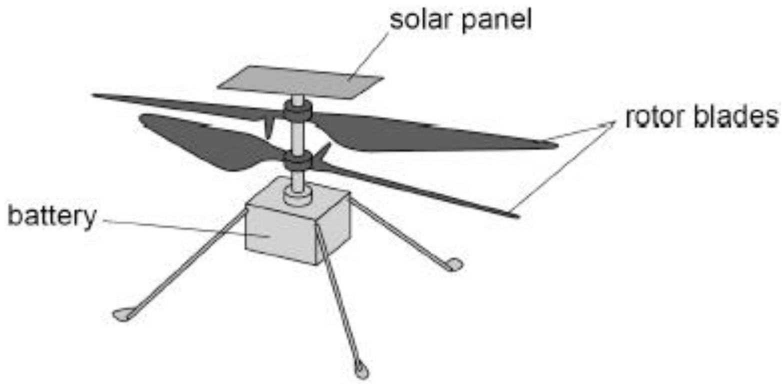
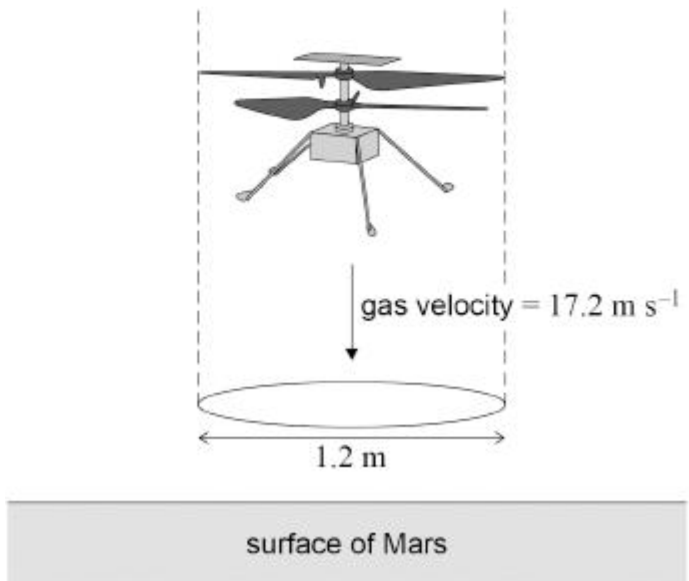


Figure 2 shows the helicopter hovering at a constant height above the surface of Mars. The rotor blades move a column of atmospheric gas vertically downwards at a velocity of 17.2 m s^{-1}. The diameter of this column is 1.2 m.

Figure 2



(a) The gas moved by the rotor blades has a density of 0.020 kg m^{-3}.

Show that the helicopter moves approximately 0.4 kg of gas every second.

(3)

The movement of the gas creates an upward force on the helicopter. This upward force enables the helicopter to hover at a constant height.

The gravitational field strength on Mars is 3.72 N kg^{-1}.

(b) Calculate the mass of the helicopter.

mass = ____________________ kg

(3)

(c) The battery stores 0.035 kW h of energy before a flight.
The flight lasts for 39 s.
The battery has a power output of 340 W during the flight.

Determine the percentage of the initial energy stored in the battery that is transferred during the flight.

percentage = ____________________ %

(2)

(d) The helicopter has a maximum flight time of a few minutes due to the limited amount of energy stored in the battery. The battery accounts for about 15% of the helicopter's mass.

A student suggests that adding another identical battery that doubles the energy available to the helicopter would double its flight time.

Deduce without calculation whether the student's suggestion is correct.

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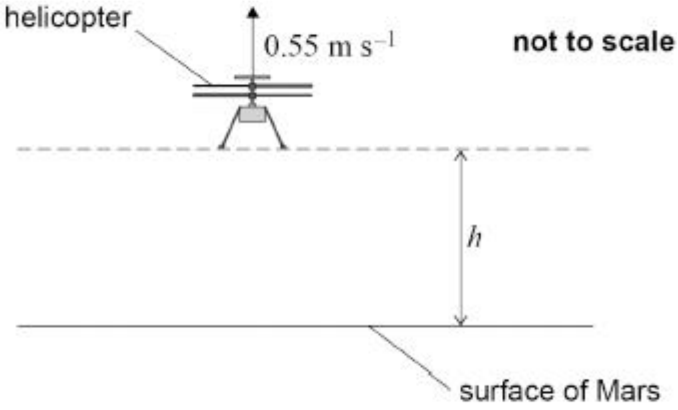
(3)

Figure 3 shows a simplified side view of the helicopter moving vertically upwards with a speed of 0.55 $\mathrm{m\ s^{-1}}$.
At the instant shown, the helicopter is at a height h and the blades stop rotating.

Figure 3



The gravitational field strength on Mars is 3.72 $\mathrm{N\ kg^{-1}}$.

The weight of the helicopter is the only force acting on it when the blades stop rotating.
Drag forces on the helicopter are negligible as it rises to a maximum height and then falls back to the surface.

(e) Calculate the time taken for the helicopter to reach its maximum height from the instant the blades stop rotating.

time = ____________________ s

(2)

(f) When the helicopter makes contact with the surface it has a velocity of 2.2 $\mathrm{m\ s^{-1}}$.

Calculate h.

h = ____________________ m

(2)

(g) A student suggests that the acceleration of the helicopter is constant from the instant the blades stop rotating until the helicopter makes contact with the surface.

Discuss this suggestion with reference to an appropriate Newton's law of motion.

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(2)
(Total 17 marks)

Q6.

A student performs an experiment to find the acceleration due to gravity. The student measures the time t for a spherical object to fall freely through measured vertical distances s. The time is measured electronically. The results are shown in the table below.

s/**m**	t_1/s	t_2/s	t_3/s	**mean time** t_m/s	t_m^2/s ^{2}
0.300	0.245	0.246	0.244	0.245	0.0600
0.400	0.285	0.286	0.286	0.286	0.0818
0.500	0.319	0.321	0.318	0.319	0.102
0.600	0.349	0.351	0.348	0.349	0.122
0.700	0.378	0.380	0.378	0.379	0.144
0.800	0.403	0.406	0.404		
0.900	0.428	0.428	0.430		

(a) Complete the table by entering the missing values for t_m and t_m^2

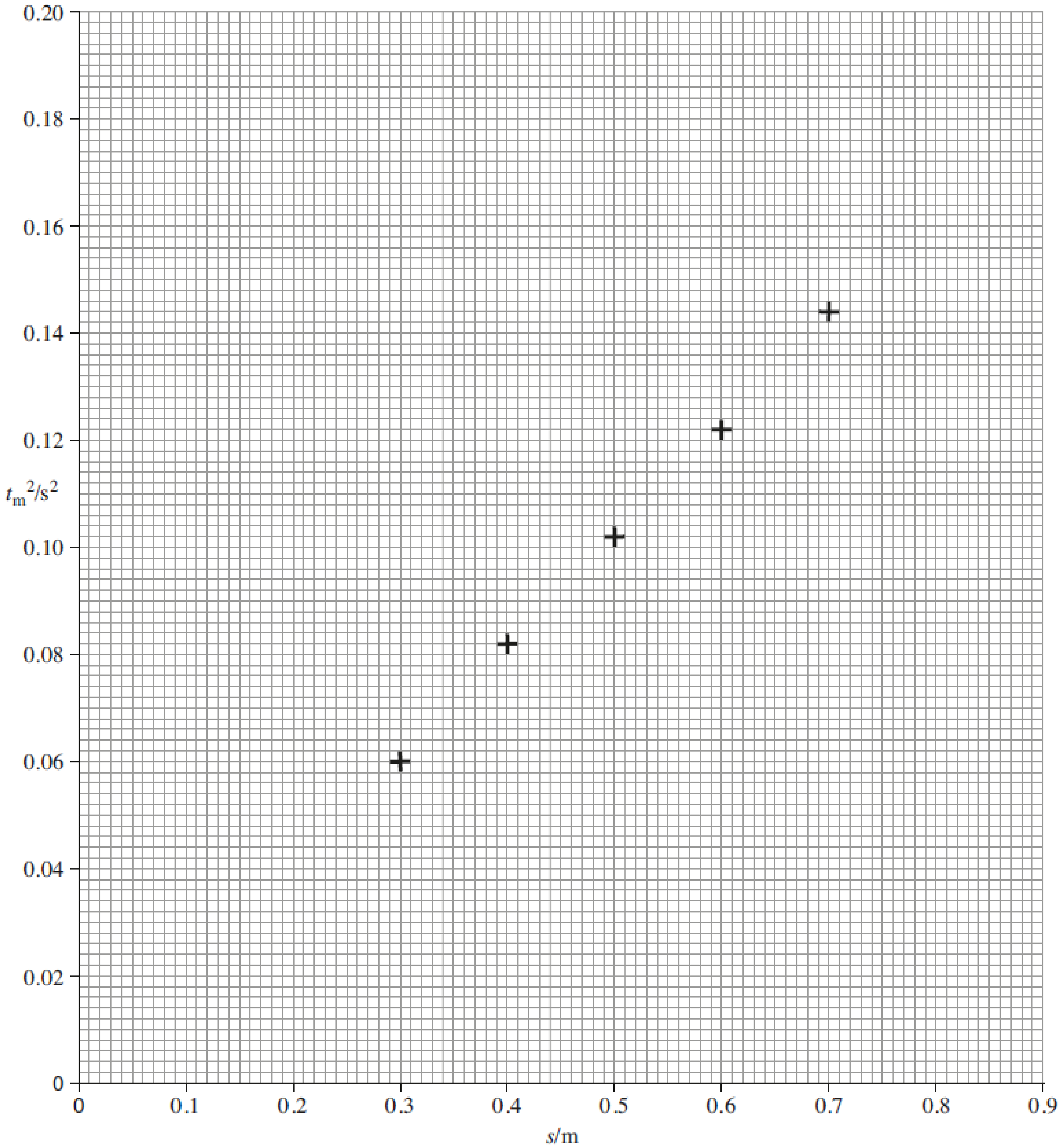
(1)

(b) Complete the graph below by plotting the remaining two points and draw a line of best fit.

(2)

(c) Determine the gradient of the graph.

(3)



(d) Theory suggests that the equation for the line is $t^2 = \frac{2s}{g}$ where g is the acceleration due to gravity.

Calculate a value for g using the above equation and the gradient of your graph above.

(1)

(e) Calculate the percentage difference between your value for g and the accepted value of 9.81 m s $^{-2}$.

(1)

(f) Calculate the uncertainty in the smallest value of t_m.

(1)

(g) Calculate the value of g which would be given from the smallest value of t_m and the corresponding value of s.

(3)

(h) The uncertainty in each value of s is ± 0.001 m.

Calculate the uncertainty in the value of g you calculated in part **(g)**.

You will need to use the uncertainty for t_m you calculated in part **(f)**.

(3)

(i) A student wishes to investigate the effect of changing the mass of the spherical object on the acceleration of free fall.

Explain how you would modify the experiment seen at the start of this question.

(3)

(Total 18 marks)

Q7.

A strain gauge is made from a constantan wire of original length 25 mm. If the wire stretches its resistance changes. The gauge is attached to an object that is then placed under tension, which causes the length of the constantan wire to increase. The resistance, R, was measured for various lengths, l, and the following results were obtained:

R / Ω	99.96	100.64	101.76	102.80	103.85	104.71
l / 10^{-2} m	2.500	2.508	2.523	2.536	2.548	2.557

When the wire is stretched, it may be assumed that for small extensions:

$$R \propto l^2$$

(a) Complete the table showing the value of l^2 for each value of R.

(2)

(b) Plot a graph of R on the y-axis against l^2 on the x-axis.

(4)

(c) Use your graph and the value for the resistivity of constantan given below to find the diameter of the wire when its resistance is 103.40 Ω.

resistivity of constantan = 4.7×10^{-7} Ωm

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(5)

(d) Define tensile strain. Use your graph to determine the strain when the resistance of the wire is 103.40 Ω.

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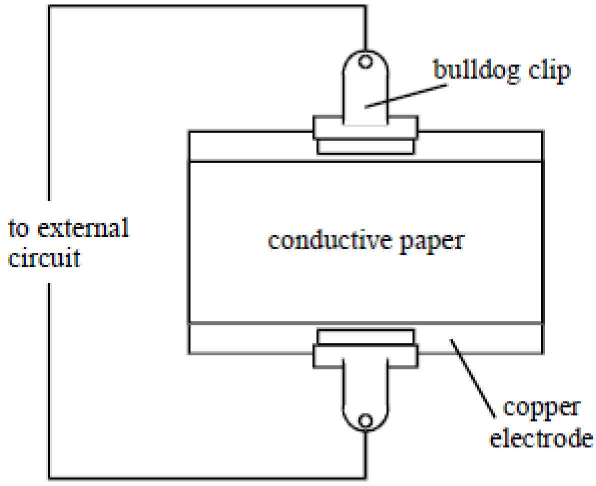
(2)

(Total 13 marks)

Q8.

Conductive paper, sometimes called *Teledeltos* paper, is produced by coating one surface of the paper with a thin layer of graphite paint. To investigate its electrical properties, pieces of the paper can be joined to a conventional wired circuit using copper electrodes and bulldog clips, as shown below.



It is known that the paper obeys Ohm's Law providing the current through it does not exceed 200 mA. The company that manufactures it estimates that under typical laboratory conditions, the resistivity of the paint is between 1.0×10^{-5} Ωm and 5.0×10^{-5} Ωm.

Design an experiment that investigates some characteristic of the conductive paper.

You should consider the following in your answer.

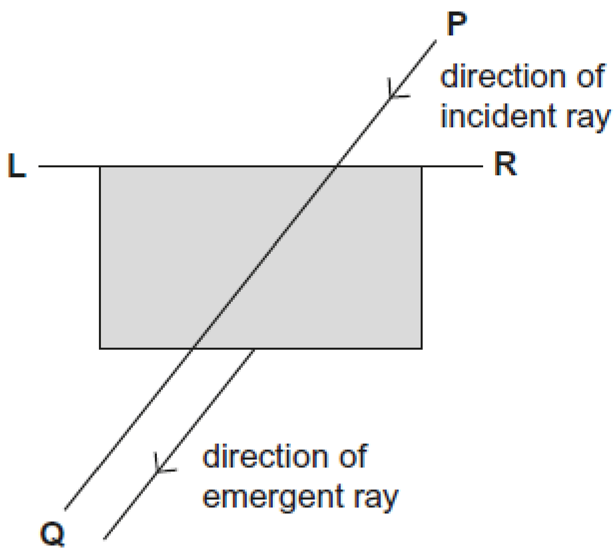
- The variables you intend to measure and how to ensure that they are measured accurately.
- The factors you will need to control and how you will do this.
- The expected outcome of the experiment that you design.
- How any difficulties in performing the experiment could be overcome.

(Total 8 marks)

Q9.

A student aligns the longer edge of a rectangular glass block along a line **LR**, as shown in **Figure 1**.

Figure 1

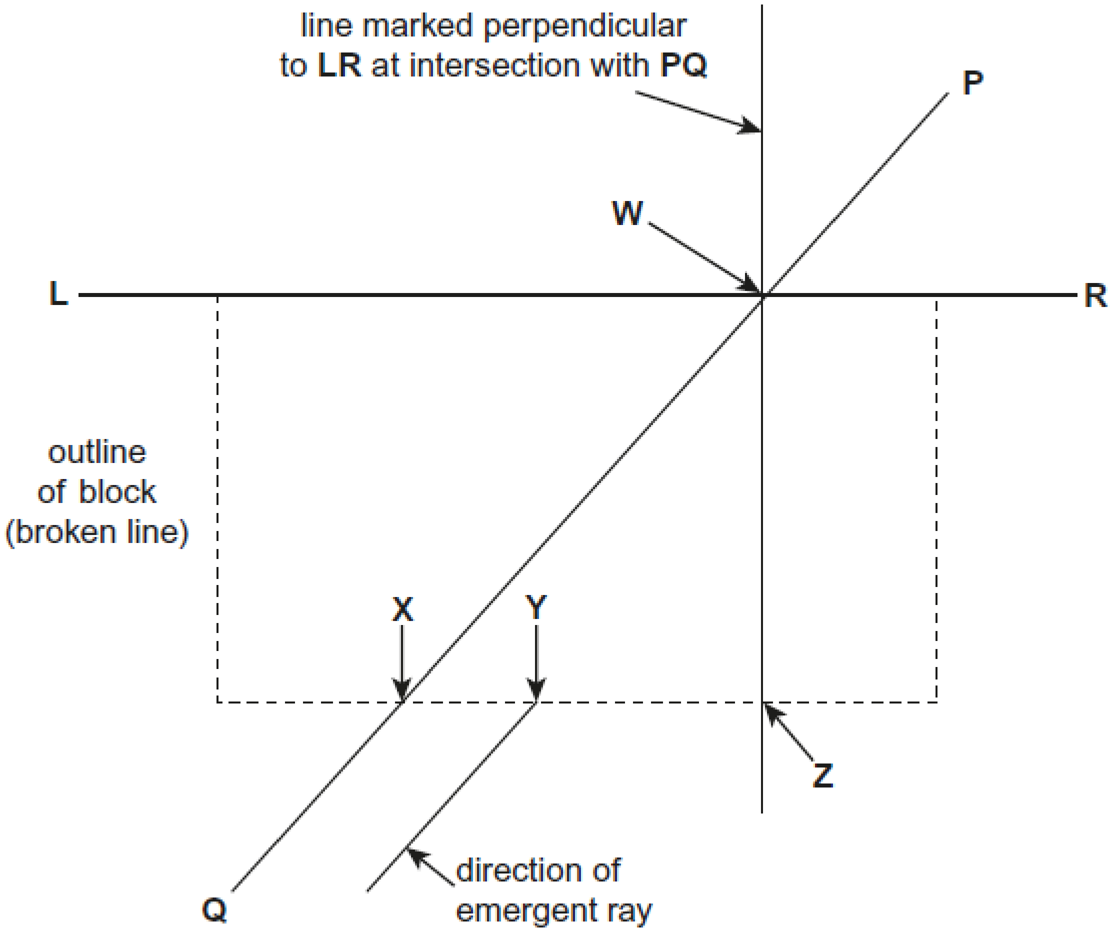


The student marks the outline of the block and directs a ray along **PQ**.

The student marks the direction of the emergent ray then removes the block and marks a line perpendicular to **LR** where **PQ** and **LR** intersect.

The student then marks the points **W**, **X**, **Y** and **Z** that are defined in **Figure 2**.

Figure 2



(a) Show that the refractive index n of the block is given by the equation

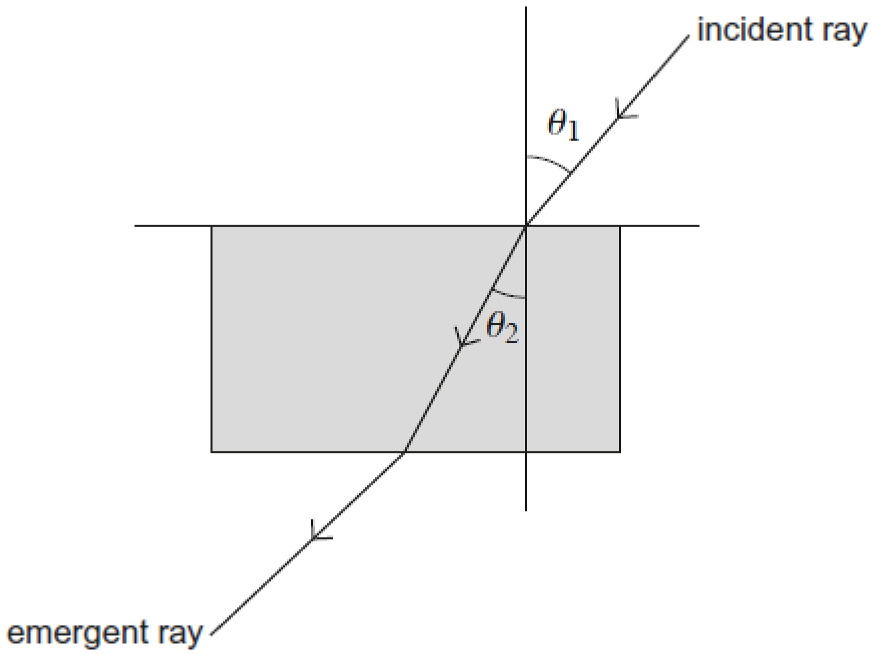
$$n = \frac{XZ \times WY}{YZ \times WX}$$

You may wish to use the equation $n = \dfrac{\sin\theta_1}{\sin\theta_2}$

where θ_1 and θ_2 are the angles shown in **Figure 3**.

You may also wish to illustrate your answer with a diagram.

Figure 3



(2)

(b) The student repeats the procedure for different directions of the incident ray **PQ**.
The student measures **XZ**, **WX**, **YZ** and **WY** for each direction of **PQ**.
State and explain how the student can use these results to obtain a value of n by a graphical method.

(2)

(c) The student used a block with dimensions 114 mm × 65 mm × 19 mm to perform the experiment.

The student's data are shown in the table below.

WX/mm	WY/mm	XZ/mm	YZ/mm
130	78	113	44
103	75	80	38
90	73	63	33
81	71	49	27
75	69	38	22
67	66	15	10

Explain whether the range of measurements made by the student is suitable.

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(3)

(Total 7 marks)

Q10.

(a)

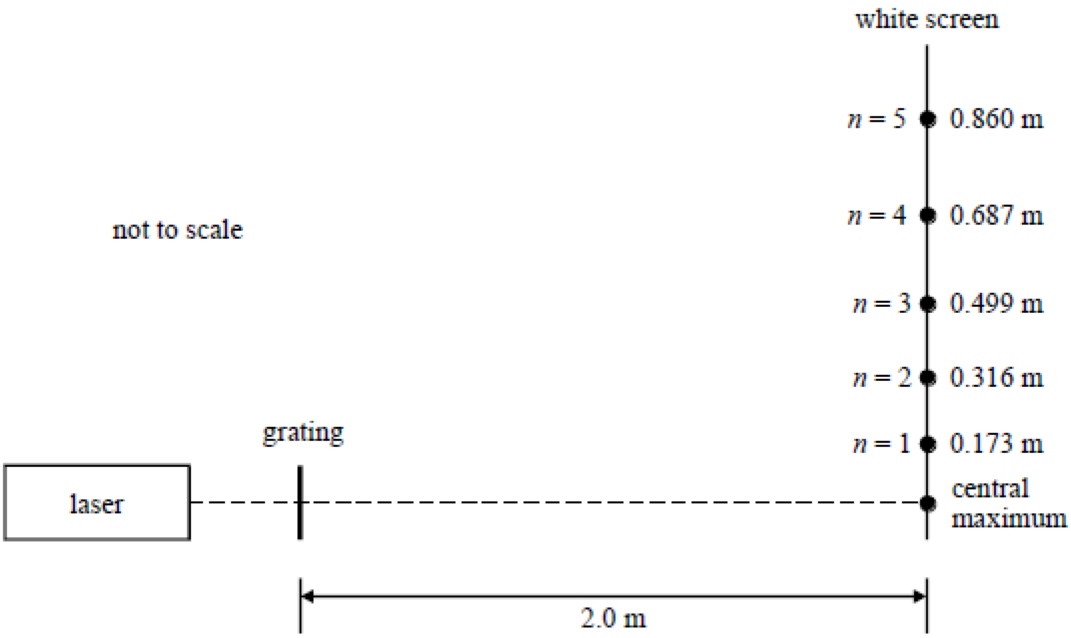
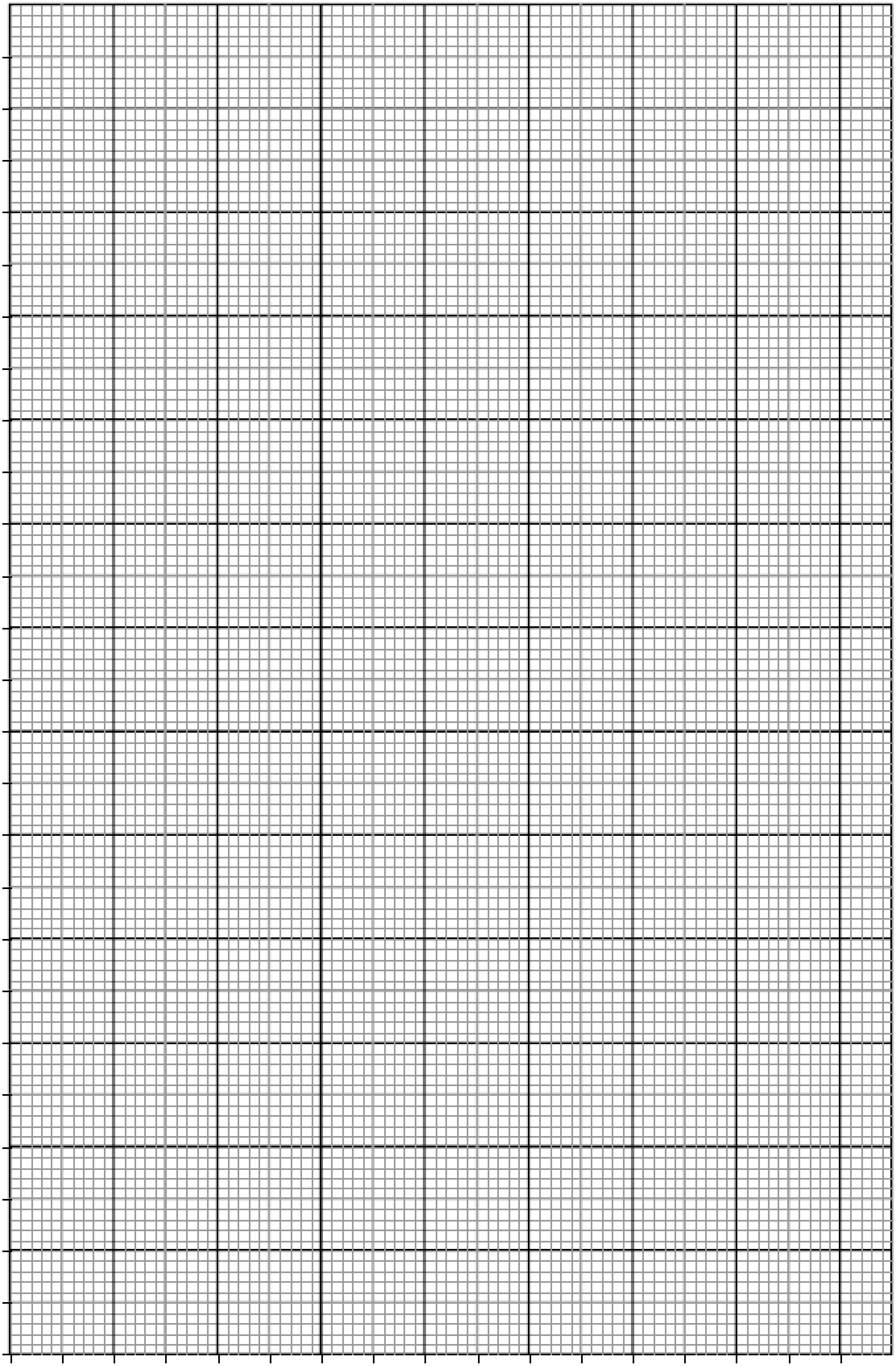


Figure 1

In a laboratory experiment, monochromatic light of wavelength 633 nm from a laser is incident normal to a diffraction grating. The diffracted waves are received on a white screen which is parallel to the plane of the grating and 2.0 m from it. **Figure 1** shows the positions of the diffraction maxima with distances measured from the central maximum.

By means of a graphical method, use all these measurements to determine a mean value for the number of rulings per unit length of the grating.



(6)

(b) Describe and explain the effect, if any, on the appearance of the diffraction pattern of

(i) using a grating which has more rulings per unit length.

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(ii) using a laser source which has a shorter wavelength.

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(iii) increasing the distance between the grating and the screen.

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(6)

(c) **Figure 2**, below, shows the diffracted waves from four narrow slits of a diffraction grating similar to the one described in part (a). The slit separation AB = BC = CD = DE = d and EQ is a line drawn at a tangent to several wavefronts and which makes an angle θ with the grating.

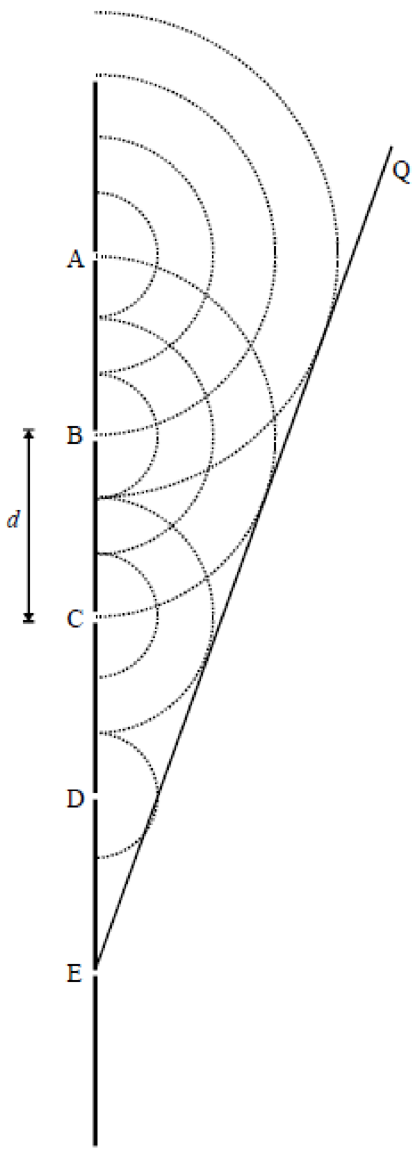


Figure 2

(i) Explain why the waves advancing perpendicular to EQ will reinforce if superposed.

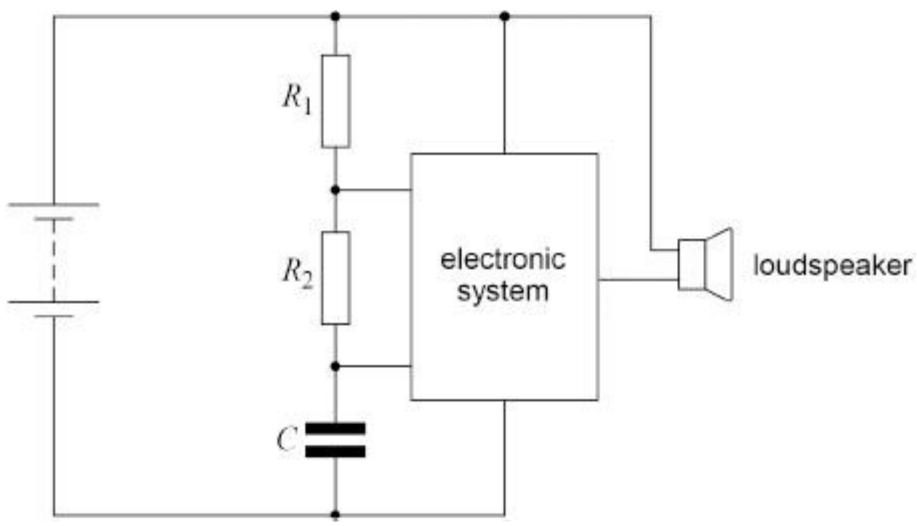
(ii) Show that this will happen when $\sin\theta = \frac{\lambda}{d}$.

(3)
(Total 15 marks)

Q11.

Figure 1 shows a circuit that causes a loudspeaker to emit 'clicks' at a constant rate. The time T between successive clicks depends on the resistances R_1 and R_2 and the capacitance C.
You do not need to know any details about the electronic system.

Figure 1



A student uses a stopwatch to determine T.
The table below shows the student's repeated measurements of $20T$.

$20T$ / s	$20T$ / s	$20T$ / s	$20T$ / s	$20T$ / s
19.22	18.91	19.36	19.04	19.45

(a) Suggest why the student measures $20T$.

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(1)

(b) Suggest why the student repeats their measurements of $20T$.

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(1)

(c) Determine the percentage uncertainty in the student's result for T.
Assume that all the data in the table above are valid.

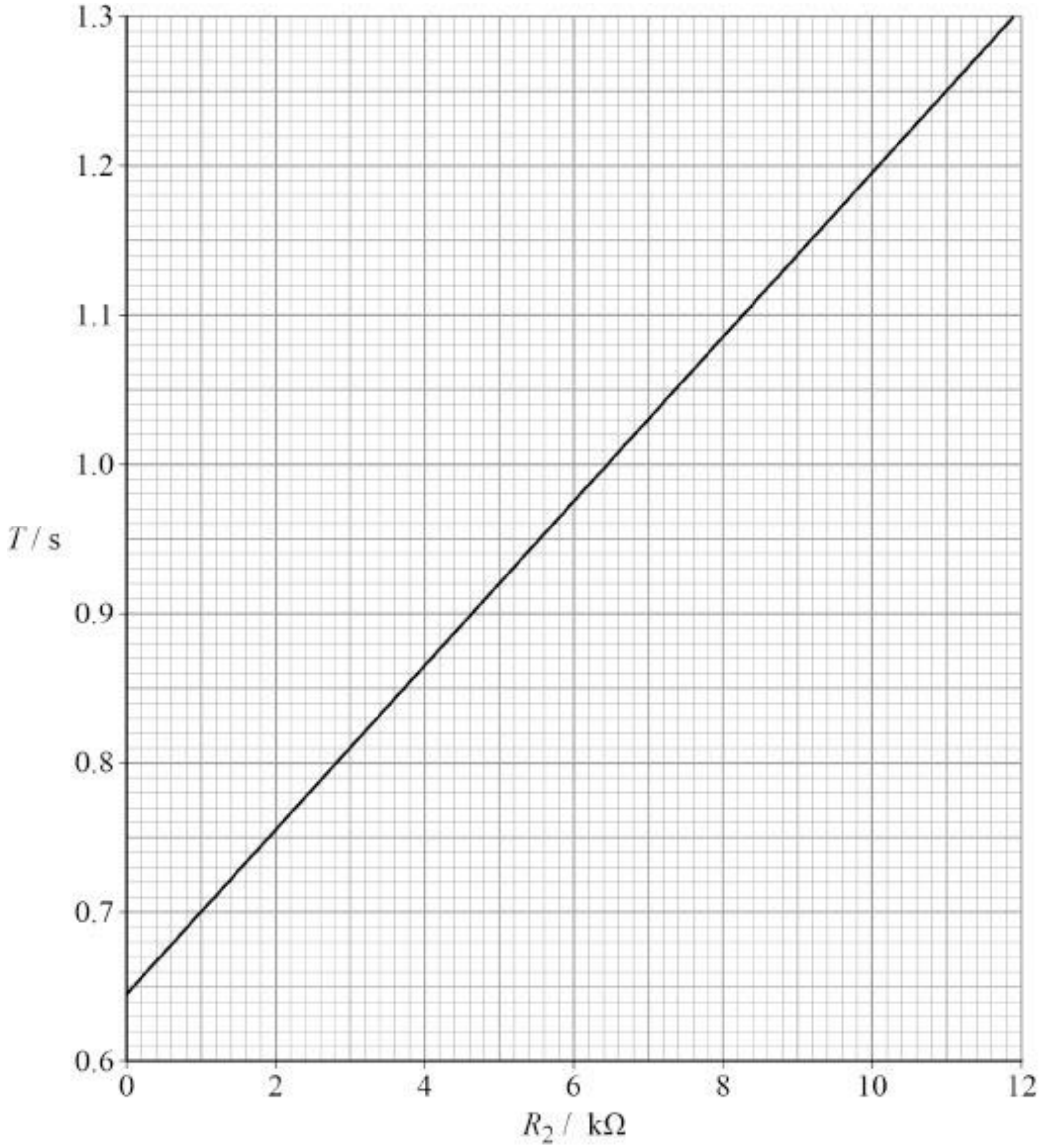
percentage uncertainty in T = ____________________ %

(2)

The student determines T for different values of R_2.
The values of R_1 and C are not changed.

The student produces the graph in **Figure 2**.

Figure 2



(d) It can be shown that

$$T = (R_1 + 2R_2)C \ln 2$$

Determine C and R_1.

C = ______________________ F

R_1 = ______________________ Ω

(5)

(e) The student has access to a range of fixed and variable resistors.
The student wants to modify the circuit in **Figure 1** so that T can be varied continuously from a minimum of 0.70 s to a maximum of 1.25 s.

Show how the student can achieve this by combining two resistors to make R_2.
You should use information from **Figure 2**.

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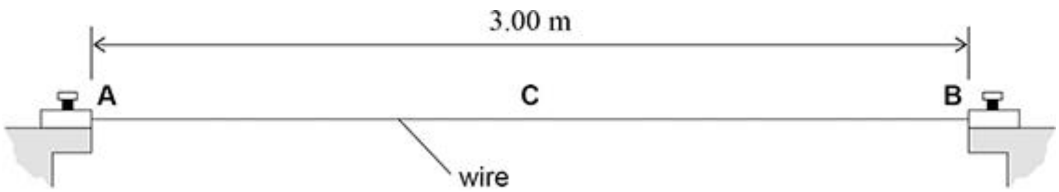
(3)
(Total 12 marks)

Q12.

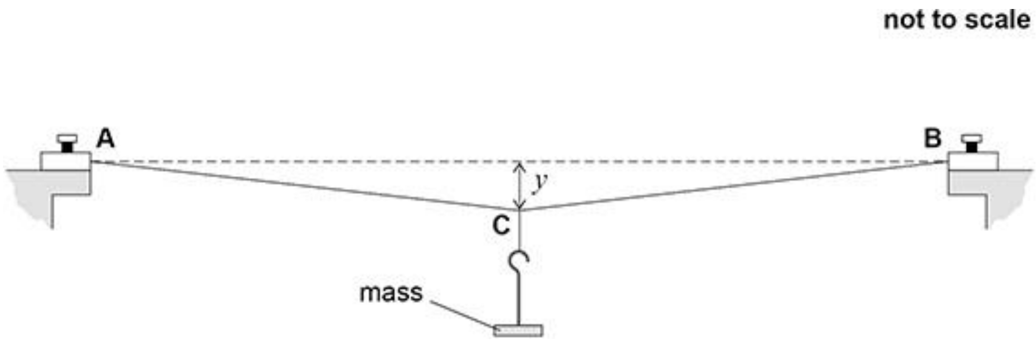
A student does an experiment to determine the Young modulus of a metal.
Figure 1 shows a wire made from the metal clamped at points **A** and **B** so that the wire is horizontal. The horizontal distance between **A** and **B** = 3.00 m.
C is the mid-point on the wire between **A** and **B**.

Figure 1



A mass of weight W is suspended at **C** to extend the wire. **Figure 2** shows that **C** moves vertically downwards by a distance y.

Figure 2



(a) When W is 1.0 N, y is 6.34 cm.

Show that the wire extends by approximately 3 mm.

(1)

(b) Calculate the tension in the wire when W is 1.0 N.

tension = _______________ N

(2)

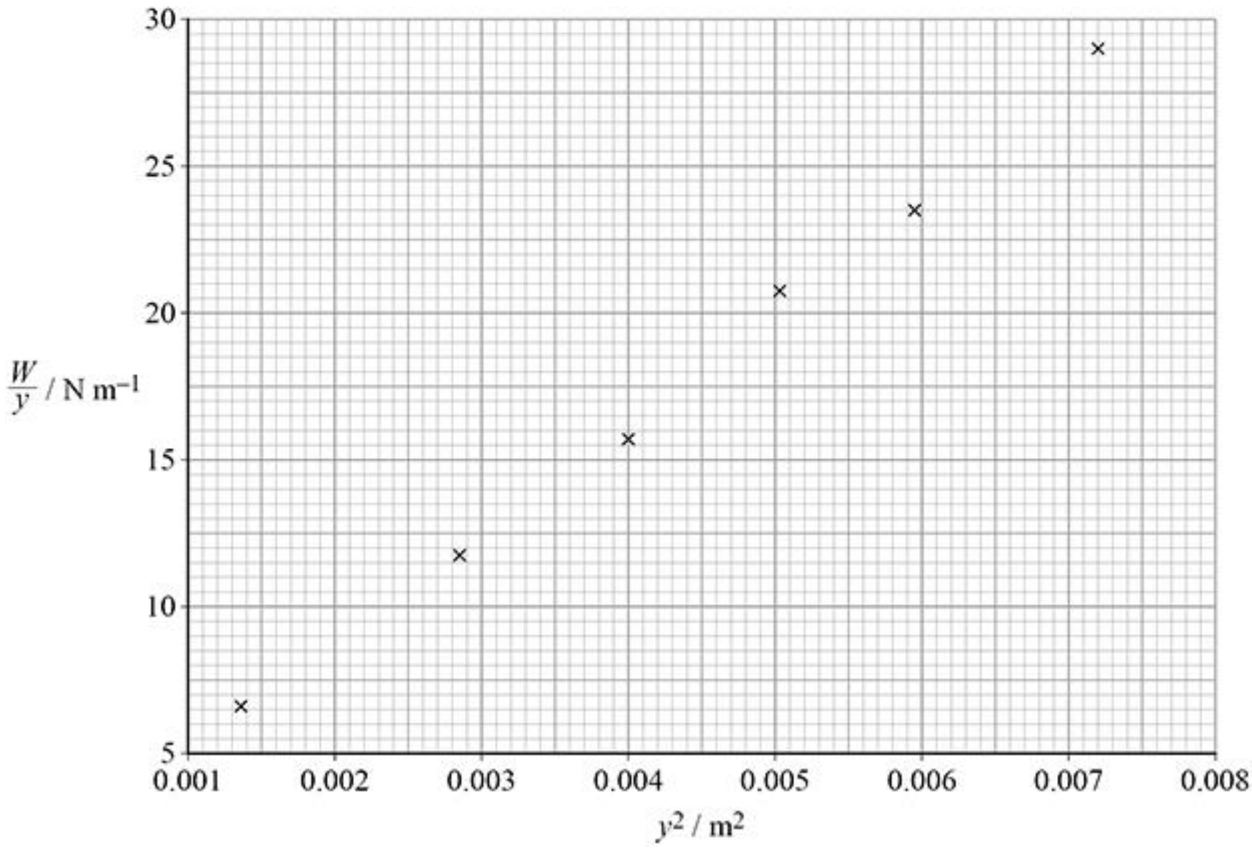
It can be shown that

$$\frac{W}{y} = \frac{EAy^2}{x^3} + k$$

where E = Young modulus of the metal
$A = 1.11 \times 10^{-7}$ m^2
x = 1.50 m
k = a constant.

A student measures y for different values of W and plots the graph shown in **Figure 3**.

Figure 3



(c) Determine E using **Figure 3**.

E = ________________ Pa

(4)

(d) Deduce the fundamental base units for k.

fundamental base units for k = _______________

(1)
(Total 8 marks)

Q13.

(a) (i) Draw and label suitable apparatus required for measuring the Young modulus of a material in the form of a long wire.

(ii) List the measurements you would make when using the apparatus described in part (i).

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(iii) Describe briefly how the measurements listed in part (ii) would be carried out.

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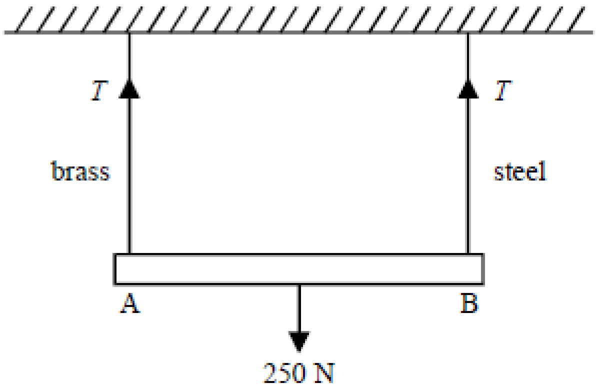
(iv) Explain how you would calculate the Young modulus from your measurements.

(13)

(b) A uniform heavy metal bar of weight 250 N is suspended by two vertical wires, supported at their upper ends from a horizontal surface, as shown.



One wire is made of brass and the other of steel. The cross-sectional area of each wire is 2.5×10^{-7} m^2 and the unstretched length of each wire is 2.0 m.

the Young modulus for brass = 1.0×10^{11} Pa
the Young modulus for steel = 2.0×10^{11} Pa

(i) If the tension, T, in each wire is 125 N, calculate the extension of the steel wire.

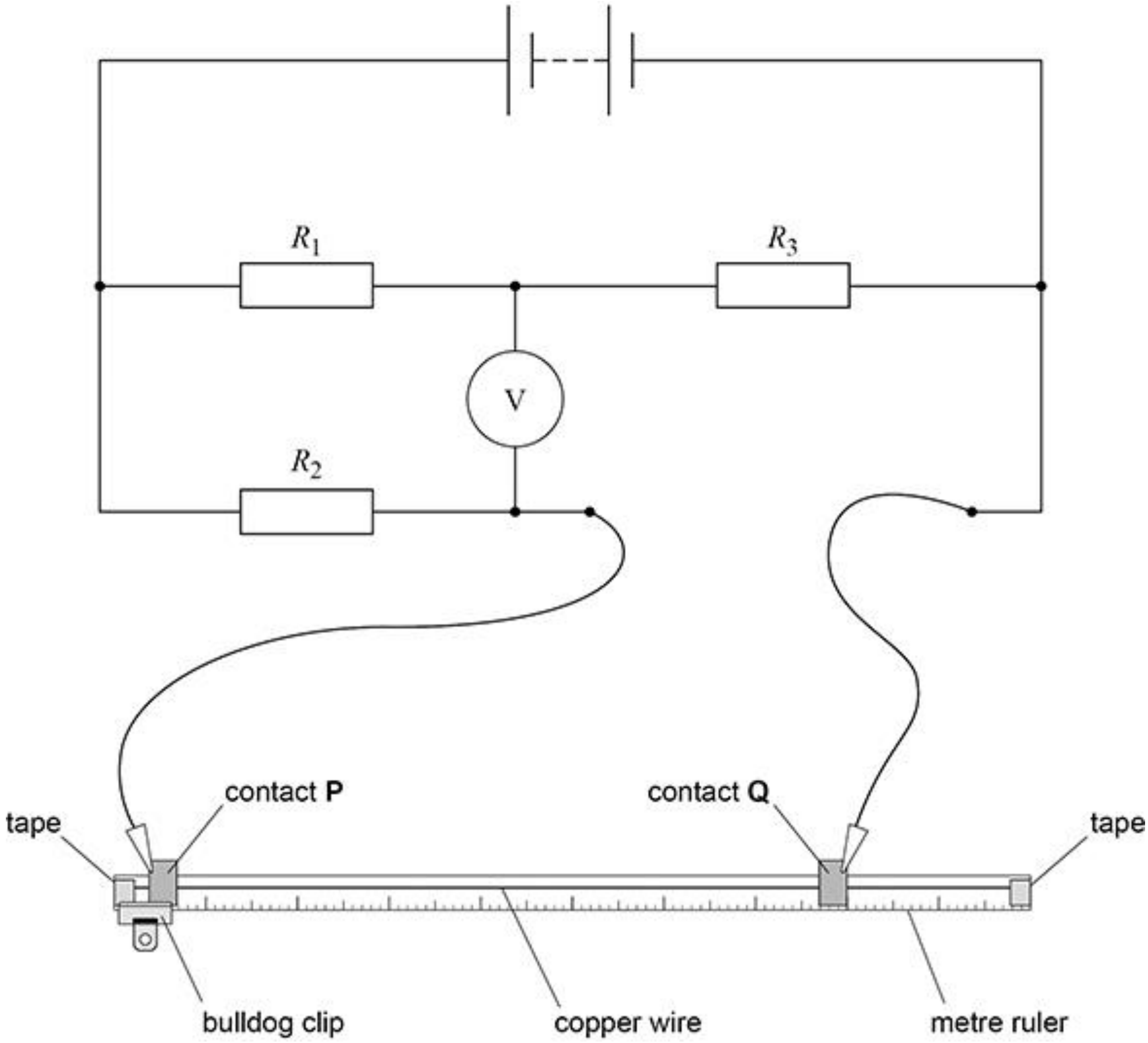
(ii) Estimate how much lower the end A will be than the end B.

(3)
(Total 16 marks)

Q14.

Figure 1 shows a circuit used to find the resistance per unit length of a copper wire.

Figure 1

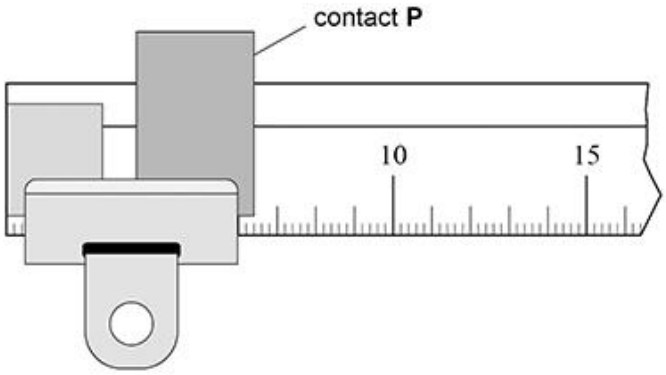


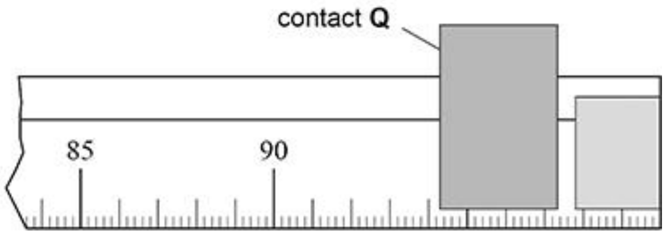
The copper wire is fixed with tape to a metre ruler that has $2\ \text{mm}$ graduations.
Contact **P** is placed on the wire close to one end of the ruler and held firmly in place using a bulldog clip.
When contact **Q** is placed on the wire as shown in **Figure 1** the voltmeter shows a non-zero reading.

Q is moved along the wire until the voltmeter reading is zero.

Figure 2 shows enlarged views of the position of **P** and the new position of **Q**.

Figure 2





(a) Determine, in m, the length x of copper wire between **P** and **Q**.

x = _______________ m

(1)

(b) When the voltmeter reading is zero:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

where R_4 is the resistance of the copper wire between **P** and **Q**.

Determine, in $\Omega\ \mathrm{m}^{-1}$, the resistance per unit length of the copper wire.

R_1 = 2.2 MΩ
R_2 = 3.9 kΩ
R_3 = 75 Ω

resistance per unit length = _______________ $\Omega\ \mathrm{m}^{-1}$

(2)

(c) The diameter d of the copper wire is approximately $0.4\ \text{mm}$.

Suggest:

- a suitable measuring instrument to accurately determine d
- how to reduce the effect of random error on the result for d.

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(3)

(d) Determine the resistivity ρ of copper.

diameter d of the copper wire = $0.38\ \text{mm}$

ρ = _______________ $\Omega\ \text{m}$

(2)

The copper wire is replaced with a constantan wire of diameter 0.38 mm.

$$\frac{\text{resistivity of constantan}}{\text{resistivity of copper}} = 30$$

(e) Suggest **one** change to the circuit to make the voltmeter read zero for the same value of x as in part (a).

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(1)

(f) Calculate, in mm, the diameter of a constantan wire that has the **same** resistance per unit length as the copper wire.

diameter = ________________ mm

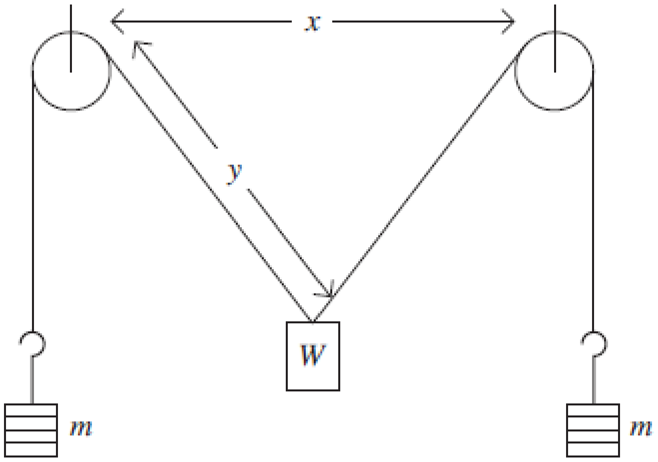
(1)

(Total 10 marks)

Q15.

In an experiment an unknown load, of weight, W, was supported by two strings kept in tension by equal masses, m, hung from their free ends, with each string passing over a frictionless pulley. The arrangement was symmetrical and is shown in **Figure 1**.

Figure 1

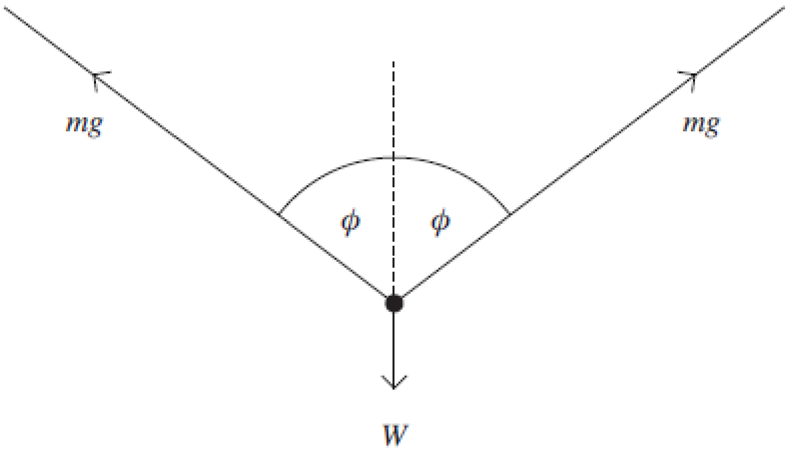


The distance x was kept constant throughout the experiment. The length y was measured for different values of m.

The distance between the strings at the pulleys, x = 0.500m

(a) **Figure 2** shows the three forces acting through the point at which the strings are attached to the load. The weight of the load is W and the tension in each string is mg, where g is gravitational field strength.

Figure 2

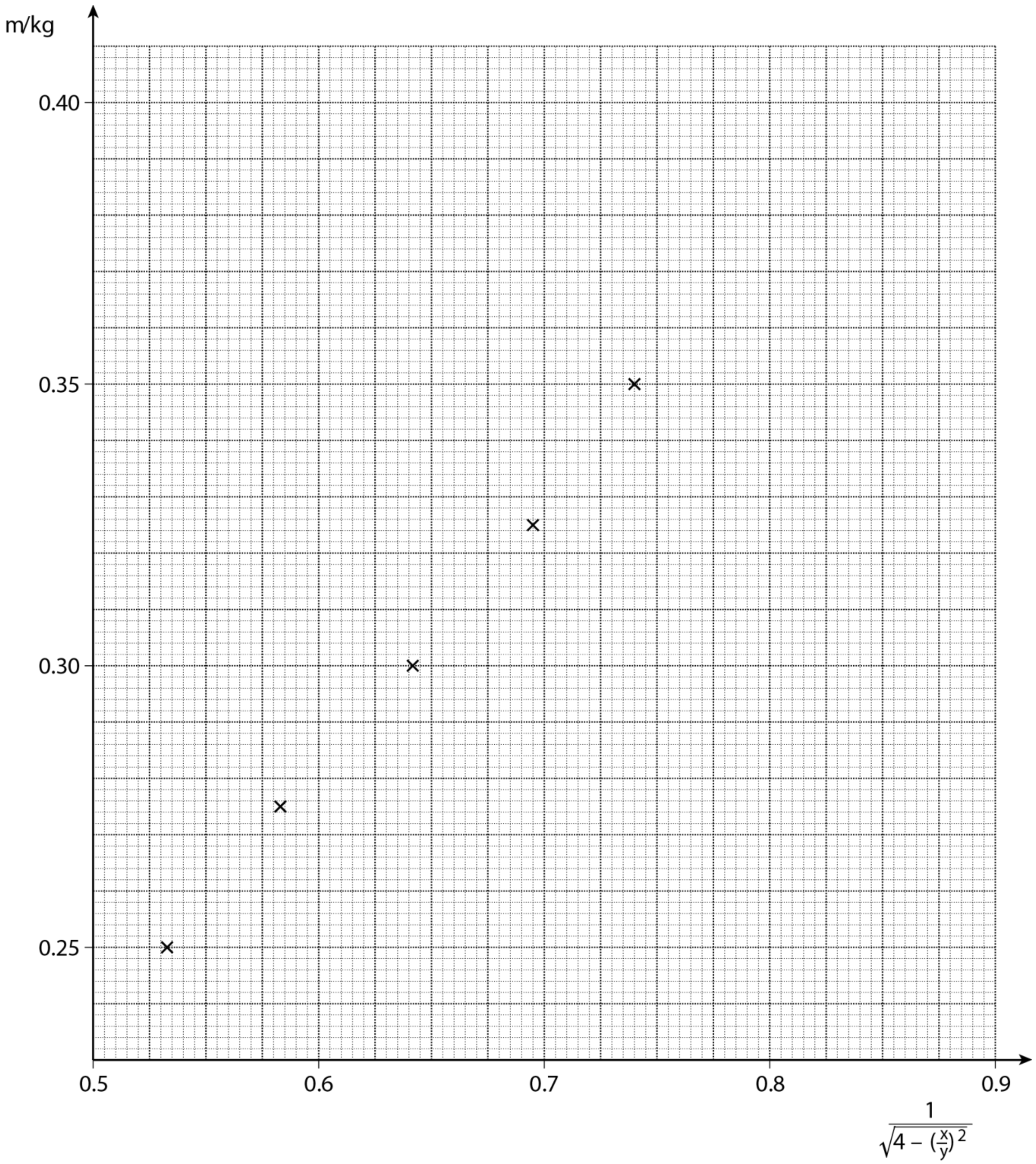


(i) By resolving the forces vertically show that $m = \frac{W}{2g\cos\phi}$

where φ is the angle between each string and the vertical.

(1)

(ii) Draw the line of best fit through the points plotted on the graph.



(1)

(b) (i) Determine the gradient of your graph.

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(3)

(ii) The equation for the straight line is $m = \frac{W}{g} \times \frac{1}{\sqrt{4 - \left(\frac{x}{y}\right)^2}}$

Given that g = 9.81Nkg^{-1}, determine a value for W.

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(2)

(c) When m was 0.300 kg, y was 0.400 m.

Calculate the percentage uncertainty in $\left(\frac{x}{y}\right)^2$ for m = 0.300 kg.

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(3)

(d) (i) Explain the term *systematic error*.

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(1)

(ii) In practice, there may be a systematic error in this experiment because of friction in the pulleys.
When the measurements were taken, increasing values of m were used. State and explain how friction in the pulleys would have affected the measured values of y.

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(2)
(Total 13 marks)

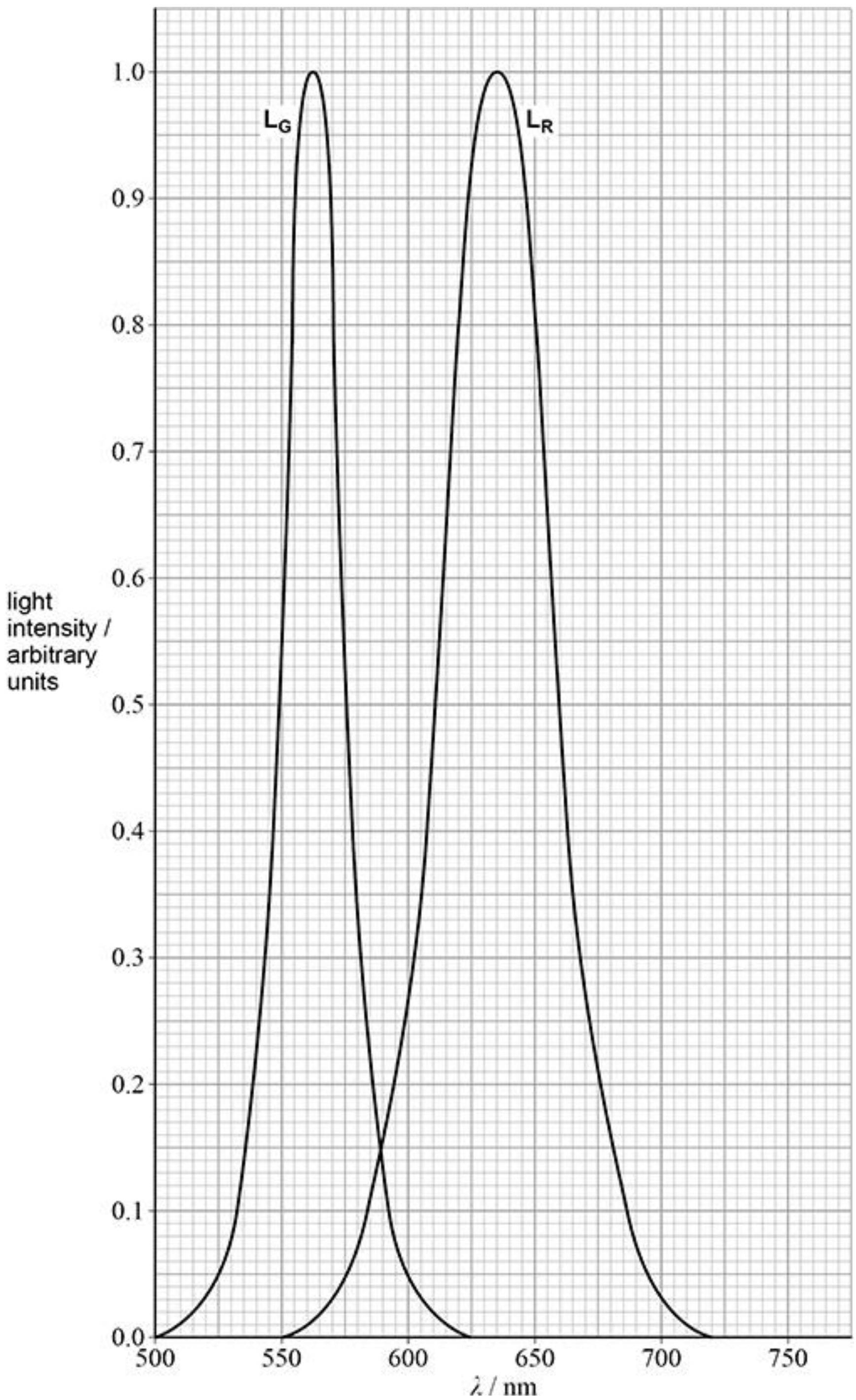
Q16.

A light-emitting diode (LED) emits light over a narrow range of wavelengths. These wavelengths are distributed about a peak wavelength λ_p.

Two LEDs $\mathbf{L_G}$ and $\mathbf{L_R}$ are adjusted to give the same maximum light intensity. $\mathbf{L_G}$ emits green light and $\mathbf{L_R}$ emits red light.

Figure 1 shows how the light output of the LEDs varies with the wavelength λ.

Figure 1



(a) Light from **L_R** is incident normally on a plane diffraction grating.
The fifth-order maximum for light of wavelength λ_p occurs at a diffraction angle of 76.3°.

Determine N, the number of lines per metre on the grating.

N = ______________ m^{-1}

(3)

(b) Suggest **one** possible disadvantage of using the fifth-order maximum to determine N.

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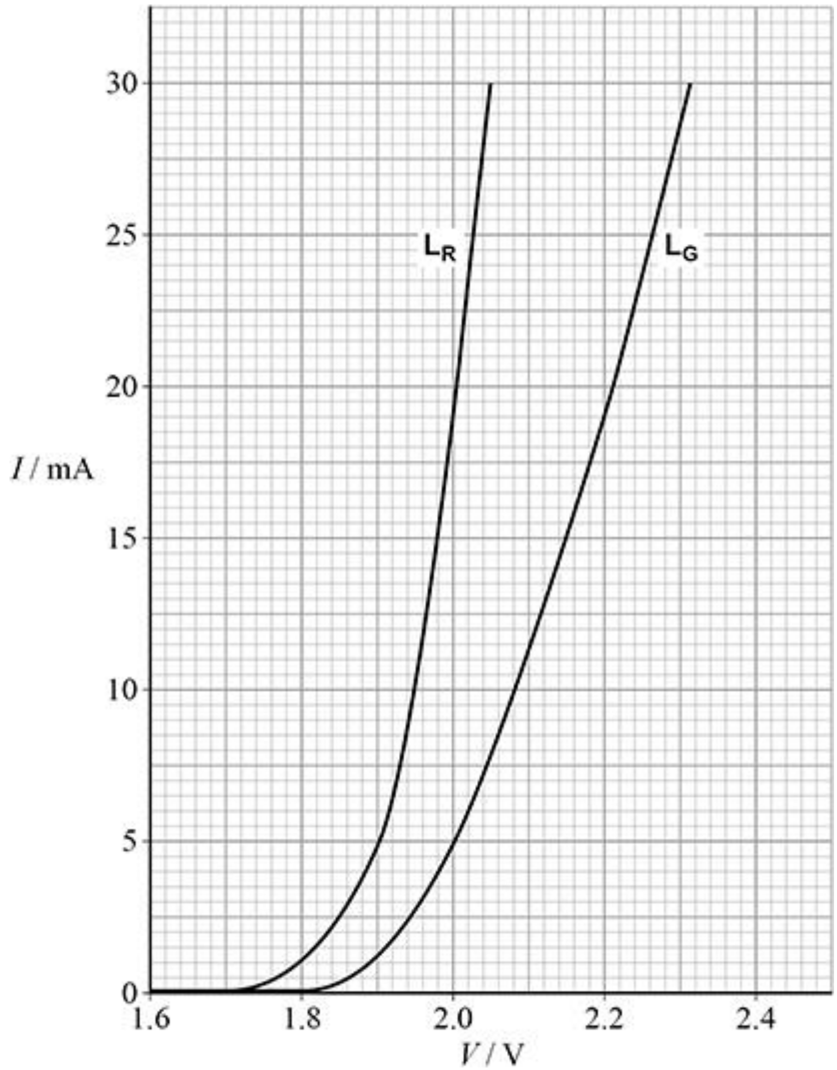
(1)

(c) **Figure 2** shows part of the current−voltage characteristics for $\mathbf{L_R}$ and $\mathbf{L_G}$.

Figure 2



When the linear part of the characteristic is extrapolated, the point at which it meets the horizontal axis gives the activation voltage V_A for the LED.
V_A for $\mathbf{L_G}$ is 2.00 V.

Determine, using **Figure 2**, V_A for $\mathbf{L_R}$.

V_A for $\mathbf{L_R}$ = _______________ V

(2)

(

d) It can be shown that:

$$V_A = \frac{hc}{e\lambda_p}$$

where h = the Planck constant.

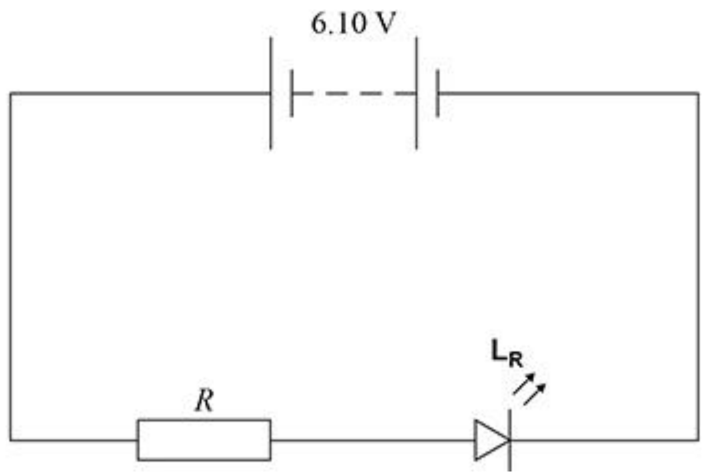
Deduce a value for the Planck constant based on the data given about the LEDs.

h = _______________ J s

(2)

(e) **Figure 3** shows a circuit with $\mathbf{L_R}$ connected to a resistor of resistance R.

Figure 3



The power supply has emf 6.10 V and negligible internal resistance.
The current in $\mathbf{L_R}$ must not exceed 21.0 mA.

Deduce the minimum value of R.

minimum value of R = _______________ Ω

(2)

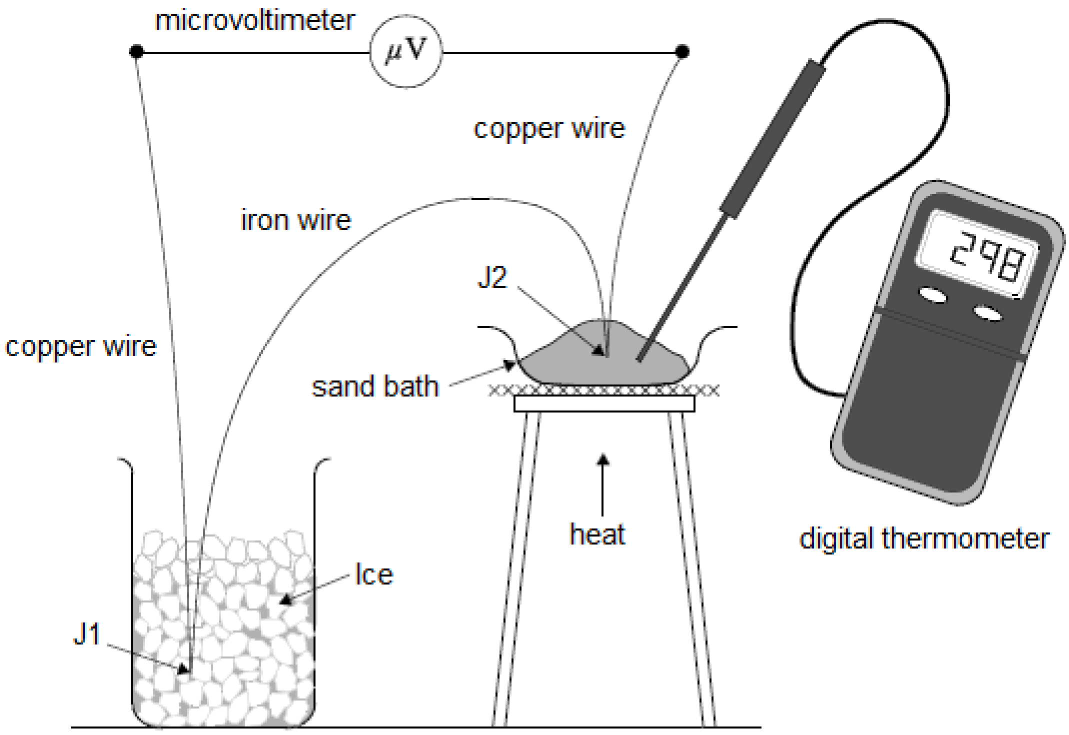
(Total 10 marks)

Q17.

Lengths of copper and iron wire are joined together to form junctions J1 and J2. When J1 and J2 are at different temperatures an emf ε is generated between them. This emf is measured using a microvoltmeter.

Figure 1 shows J1 kept at 0 °C while J2 is heated in a sand bath to a temperature θ measured by a digital thermometer.

Figure 1

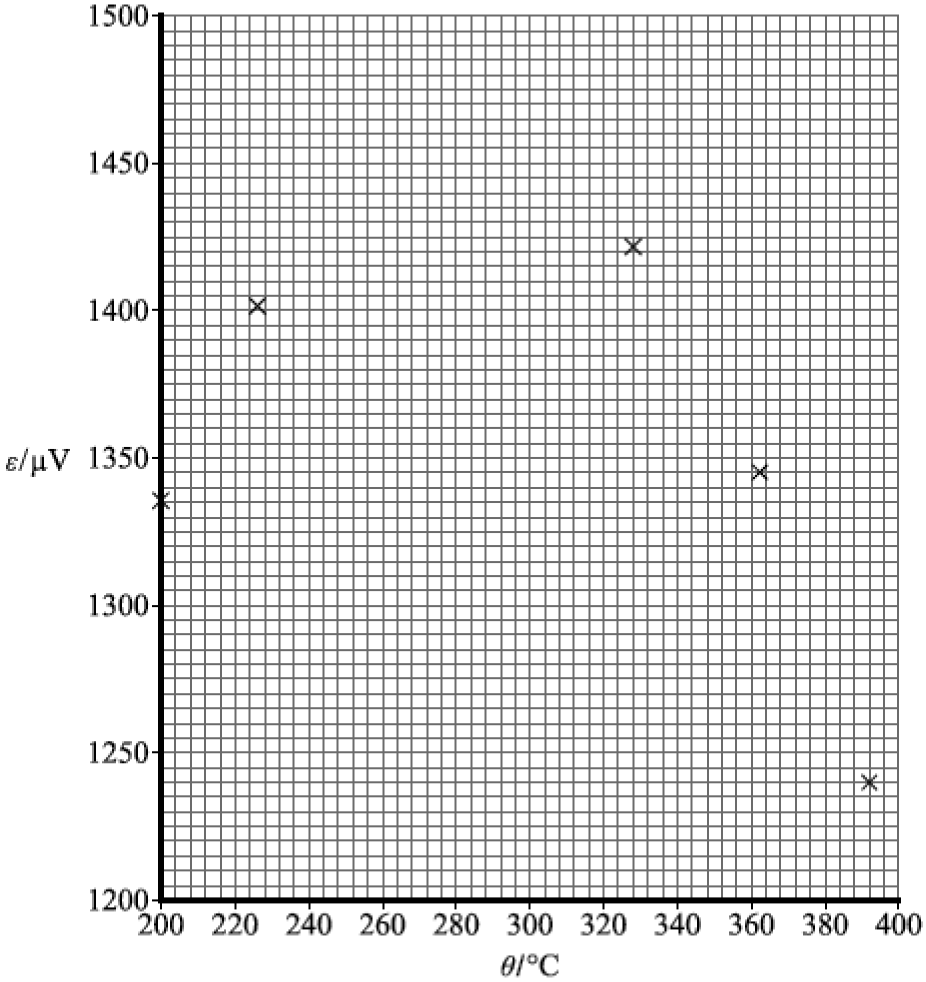


An experiment is carried out to determine how ε depends on θ.

The results of the experiment are shown in the table below and a graph of the data is shown in **Figure 2**.

θ / °C	ε / μV
200	1336
226	1402
258	1450
298	1456
328	1423
362	1345
392	1241

Figure 2



(a) Plot the points corresponding to θ = 258 °C and θ = 298 °C on **Figure 2**.

(1)

(b) Draw a suitable best fit line on **Figure 2**.

(1)

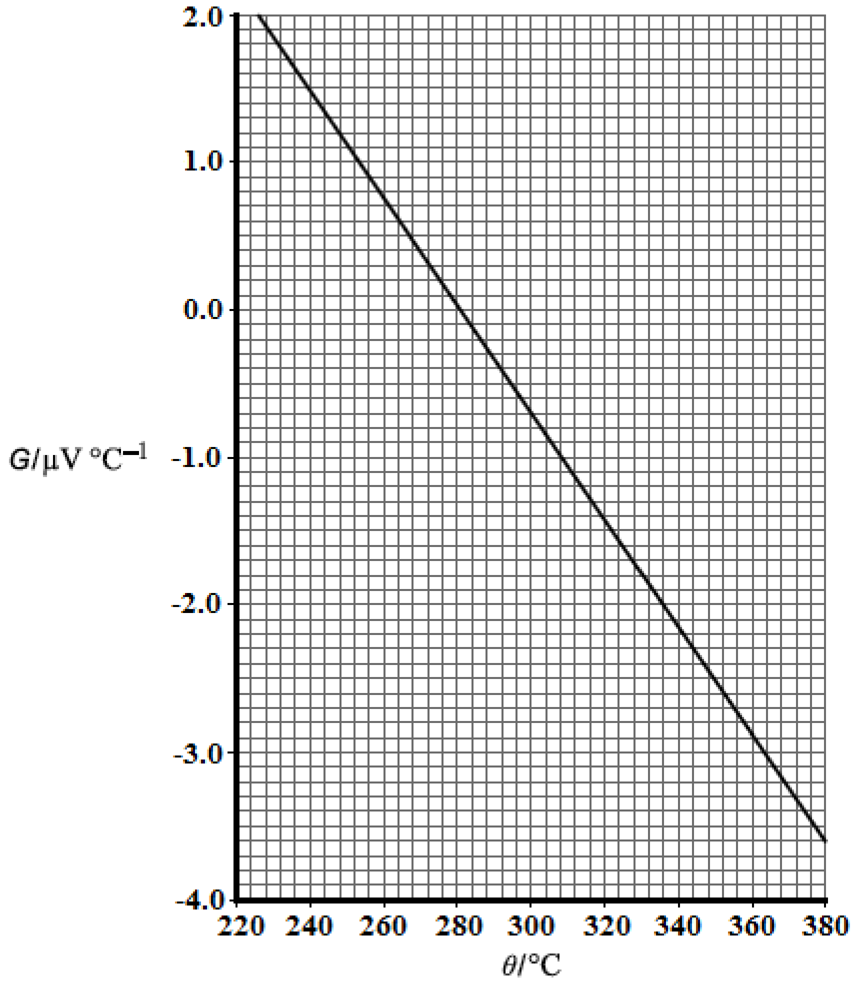
(c) Determine the maximum value of ε.

maximum value of ε = ____________________ μV

(1)

(d) The gradient G of the graph in **Figure 2** is measured for values of θ between 220 °C and 380 °C. A graph of G against θ is plotted in **Figure 3**.

Figure 3



The neutral temperature θ_n is the temperature corresponding to the maximum value of ε. θ_n can be determined using either **Figure 2** or **Figure 3**.

Explain why a more accurate result for θ_n may be obtained using **Figure 3**.

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(1)

(e) It can be shown that G is given by

$$G = \beta\theta + \alpha$$

where α and β are constants.

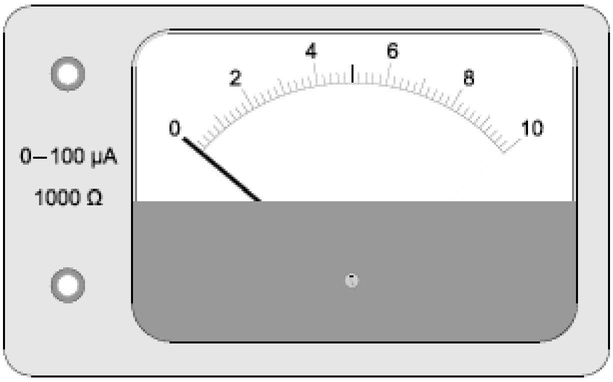
Determine α.

α = ____________________ $\mu V\ °C^{-1}$

(2)

(f) A student decides to carry out a similar experiment. The student thinks the meter in **Figure 4** could be used as the microvoltmeter to measure ε.

Figure 4



When this meter indicates a maximum reading and the needle points to the right-hand end of the scale (full-scale deflection), the current in the meter is 100 μA. The meter has a resistance of 1000 Ω.

Calculate the full-scale deflection of this meter when used as a microvoltmeter.

full-scale deflection = ____________________ μV

(1)

(g) The scale on the meter has 50 divisions between zero and full-scale deflection.

Discuss why this meter is not suitable for carrying out the experiment.

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(2)

(Total 9 marks)

Mark schemes

Q1.

(a) <u>Award each mark independently</u>

Lepton number not conserved therefore not possible ✓

Lepton numbers for particles correct ✓

Any incorrect quantum number equation (for Q, B or S) loses MP2.

Eg $0 = 1 -1 -1$ (for lepton number)

OR $0 = 0 -1 +0$ (for muon lepton number)

Alternative for MP2

reference to missing <u>muon neutrino</u> in order to balance/conserve (muon) lepton number.

2

(b) up anti-up

AND

down anti-down ✓

Either order

Credit symbols

But do not condone any use of capital letter

1

(c) Identification of quarks in either neutral kaon correct, ie kaon $d\,\bar{s}$

OR anti-kaon $\bar{d}\,s$ ✓

Identification of quarks in other kaon correct, with statement that they are not the same. ✓

Alternative:

Kaon has strangeness +1 ✓

Anti-kaon has strangeness –1 and is therefore not the same. ✓

Allow max 1 if

- *quark configurations wrong way round.*
- *value of strangeness is wrong way round*
- *statement that strangeness is different without reference to value.*
- *strangeness and quarks given but one of them is incorrect.*

2

(d) <u>Award each mark independently</u>

Links hadrons to strong nuclear force (snf)

OR identifies snf as forcing holding nucleus together ✓

OR

(only) pion and muon have correct rest energy with no mention of kaon.

Reason why it cannot be the kaon ✓

For MP2: kaon rest energy is not between those of electron and half that of nucleon. (values quoted from data booklet)

Reason why it cannot be the muon ✓

For MP3: muon is a <u>*lepton*</u> *(and does not experience snf)*

pion is the particle as it (has mass in range and) is a <u>hadron</u> (and therefore experiences snf) ✓

An incorrect statement amount a particle negates the mark for that particle.

Rest energies/MeV:

kaon 493.821 or 497.762

pion 139.576 or 134.972

muon 105.659

nucleon 938.257 or 939.551

4

[9]

Q2.

(a) $^{4}_{2}\alpha$ ✓ + $^{234}_{90}\mathrm{Th}$ ✓

1 mark each for alpha and Th; numbers must be correct

Must see "+" for full marks

Condone He for alpha

If no other mark is given, one mark can be awarded if He-3 is used and A and Z are correct

MAX 1 for extra particles but condone "+ $2e^{(-)}$" (not 2β)

Ignore symbol that is used for Thorium

2

(b) Idea that a neutron changes to proton/beta minus decay ✓

The particle is W- because

For MP1 condone "down quark changes to up quark".

Evidence for MP1 can be found in the form of equations or diagrams.

This is a weak interaction / it involves the weak force / there is a quark change

and indication that charge is conserved ✓

Second mark requires some explanation of why particle is negative.

MAX 1 for a complete consistent inverse interaction leading to W^{+}.

2

(c) (*FOR*:)

Lines **C** is in (both) hydrogen (and helium spectra)

OR

Line **E** is in (both) sodium (and helium spectra) ✓

(*AGAINST*:)

Line **D** is missing (is in neither the hydrogen nor the sodium spectra) ✓

*Treat references to **A**, **B** and **F** in FOR or AGAINST as neutral.*

Must link line to an element

Ignore any discussion of any "missing" lines in the helium spectrum.

*Condone use of 390 / 440 / 490 / 505 / 590 / 670 (nm) for **A/B/C/D/E/F***

Condone emission for absorption

2

(d) Wavelength = 580 nm to 590 nm ✓

Use of $E = hc/$(their wavelength) ✓

Conversion of their E in J to eV ✓

Expect to see answer in range 2.11 to 2.14 (eV)

When an energy difference between two spectral wavelengths is correctly calculated, only MP2 and MP3 can be scored.

3

(e) Photon is energy carrier OWTTE ✓

In absorption atom becomes excited/moves to higher energy state/level (by absorbing photon) ✓

In emission atom de-excited/moves to lower energy state (by emitting photon) ✓

Treat discussion of any other irrelevant phenomenon or incorrect physics as talk out in that marking point.

Allow "energy shell" but not "shell".

Condone electron for atom.

Suggestions that limit transitions to/from ground state penalise in either MP2 or MP3 once only.

Condone omission of reference to energy states/levels in either MP2 or MP3 but not both.

3

[12]

Q3.

(a) attempt to determine horizontal component of velocity

OR

multiplies their speed by 1.7 (s) $_1$✓

For $_1$✓, $\frac{8.7}{\tan 73°}$ or 8.7tan17° or 2.66 m s^{-1} seen.
For $_1$✓: for their speeds accept only the horizontal component (2.66 m s^{-1}) or the initial speed ($\frac{8.7}{\sin 73°}$ or 9.0975 m s^{-1}). Condone 8.7cos73° (2.54 m s^{-1}).

4.5 (m) $_2$✓

For $_2$✓ calculator value = 4.52176 (m)

2

(b) Max 2 from: $_1$✓$_2$✓

use of $s = ut + \frac{1}{2}at^2$ $_a$✓

consistent use of vector signs for u and a in above equation $_b$✓

For $_a$✓ must see substitution of 1.7 for t and a value for u.
Expect u = 8.7; condone 8.7sin73°. Allow g/9.8/9.81 for a.
Allow alternative method for $_a$✓ and $_b$✓:
use of suvat equations to get time to max height (expect 0.887 s from 3.858 m) ✓

correctly takes into account of 3.1 m (e.g. uses s = 3.1−h) $_c$✓

uses 1.7 - their calculated t to get distance from max height to basket (expect 3.243 m) ✓

2.5 (m) $_3$✓

2.5 (m) with some relevant working gets all 3 marks

3

(c) (lower launch angle means) larger horizontal component of (initial) velocity **OR** smaller vertical component of (initial) velocity $_1$✓

Condone 'speed' for 'velocity'.

(so) shorter time of flight, so fewer images $_2$✓

2

(d) Max 3 from: $_1$✓ $_2$✓ $_3$✓

idea that (magnitude of) air resistance depends on speed **OR** that air resistance (always) acts against direction of motion $_a$✓

idea that, when s_v is increasing, a_v is larger (than g/9.81) because air resistance acts downwards / same direction as weight $_b$✓

idea that, when s_v is decreasing, a_v is smaller (than g/9.81) because air resistance acts upwards / in opposite direction to weight $_c$✓

For $_b$✓ or $_c$✓ allow comparison that a_v during increasing s_v is greater than a_v during decreasing s_v

description of how a_v changes (because of air resistance) with speed during increasing s_v or decreasing s_v $_d$✓

e.g. for $_d$✓ 'as s_v decreases, a_v decreases as the speed increases'

3

[10]

Q4.

(a) calculates, using all 4 values, a mean of 0.418 (s) ✓

Expect to see 25.08 (mean average) divided by 60, or 100.32 (sum) divided by 240 in working

1

(b) 2.75 cycles (between **P** and **Q**) $_1$✓

T_{PQ} = 0.42 × their number of cycles $_2$✓

Expect T_{PQ} = 1.15, 1.16 or 1.2 (s)

$_2$✓ Allow use of >2 sf T_{PQ} that rounds to 0.42 (s)

$_2$✓ Their number of cycles must be between 2.5 and 3

2

(c) 0.170 (m) ✓

Condone 2 sf value on answer line if working shows a 3 sf value or "170 mm" seen or "20 mm" used e.g. '8.5 × 20 mm'.

1

(d) correct use of an appropriate equation of motion $_1$✓

correct evaluation of their *a* $_2$✓

Expect to see a = 0.24, 0.25 or 0.26 (m s^{-2})

$_1$✓ Expect $a = \dfrac{2 \times \text{their } s}{\text{their } (T_{PQ})^2}$ ***OR***

mean $v = \dfrac{\text{their } s}{\text{their } T_{PQ}}$ ***AND*** $a = \dfrac{2 \times \text{their mean } v}{\text{their } T_{PQ}}$

Expect mean v = 0.14 or 0.15 (m s^{-1})

$_1$✓ Allow s in mm

2

(e) links (absolute) uncertainty of 1 mm for one reading to the resolution of 2 mm of the graph paper $_1$✓

$_1$✓ Condone 'uncertainty in a single reading is half a grid division'

idea that *s* is based on two readings so (absolute) uncertainties in each reading are added $_2$✓

$_2$✓ Allow 's is based on two readings so uncertainty in s is double the uncertainty of each reading'

2

(f)

$$\frac{0.002}{their\ s} \times 100$$

OR

2 × 0.46 or 0.92 seen $_1$✓

Expect to see % uncertainty in a = 2.1

$_1$✓ Expect % uncertainty in s = 1.2. Calculator value is 1.17647.

$_1$✓Allow values in mm

% uncertainty in *a* = (their % uncertainty in *s*) + 0.92 $_2$✓

$_2$✓ Allow 1 or 2 sf values only

2

(g) resultant force should be lower $_1$✓

*$_1$✓ Default interpretation of “;a” is the experimental value (from **part (d)**) unless otherwise defined.*

$_1$✓ Allow idea that experimental value of a would be larger in absence of friction.

$_1$✓ Credit algebraic expression that includes friction (F): ma = mgsinθ - F. Condone missing “m”.

(student's value of) *g* is less (than 9.81 m s^{-2}) $_2$✓

$_2$✓ is contingent on $_1$✓

2

[12]

Q5.

(a) (Use of volume (per sec) =) $\frac{\pi d^2}{4}$ × 17.2 ✓

(Volume per second =) 19.45 (m^3 s^{-1}) = $\frac{774\pi}{125}$

$\frac{\pi d^2}{4}$ × 17.2 = $\frac{9\pi}{25}$ × 17.2

Use of *ρ* = $\frac{m}{V}$✓

Substitutes their volume (per second) and density where $\frac{m}{t}$ would be subject. Do not award MP2 if 2 errors are made in substitution.

(mass per second =) 0.389 (kg s^{-1}) ✓

Answer seen to at least 2 sf.

Calculator display = 0.3890548342

3

(b) Use of *F* = $\frac{m}{t}$ × *v* or (*F* =) 6.69 N or 6.708 (N) or 6.88 (N)

OR

Use of *W=mg*

OR statement:

Upward force = weight ✓

Possible ECF from ***(a)*** *where their m rounds to 0.4 kg.*
W = 3.72m seen or 3.72m as the subject of a force equation.
Do not allow 3.72 x 0.4 as use of W=mg
.

Applies condition for equilibrium by setting *F* = *mg*

OR

6.69 = 3.72 *m or* 6.708 = 3.72 *m* or 6.88 = 3.72 *m*✓

(*m* =) 1.80 (kg) ✓

Accept answer correctly rounded to at least 2 sf.
F= 6.88 N where $\frac{m}{t}$ *= 0.4*
m=1.85 kg or 1.8 kg

3

(c) Use of *E* = *Pt*

OR

converts kWh to J ✓

(E =) 340 × 39 ***or*** *13260 (J)*
(0.035 kWh =) 35 × 3600 ***or*** *126000 (J)*
Alternative MP1 *converts to any of the following units of energy.*
- *0.34 (kW) x 0.0108 (h)* ***or*** *0.00368 (kWh)*
- *0.035 kWh = 35 (Wh)*
- *340(W) ×* $\frac{13}{1200}$ *(h)* ***or*** $\frac{221}{60}$ *(Wh) or 3.683 (Wh)*

Or equivalent e.g W mins
Do not accept incorrect unit.
Do not accept incorrect subject.

MP2

Do not allow answers obtained using incorrect power $\left(\frac{126000}{39}\right)$
$\frac{340}{incorrect\ power}$ *such as* $\frac{340}{\frac{126000}{39}}$

(=) 11% ✓

Accept answer correctly rounded to at least 2 sf.
Calculator display = 10.5238

2

(d) Incorrect:

- this will increase weight **OR** helicopter must provide a greater lift **OR** (more mass therefore) greater GPE (for same height) **OR** (more mass therefore) greater KE (for same speed) **OR** idea that more energy is required. ✓
- the helicopter must displace more (atmospheric) gas (every second to produce greater lift force) **OR** blades must spin faster✓
- the helicopter must do more work every second (so will transfer stored energy at a greater rate) **OR** the helicopter needs more power to fly✓

OR

Incorrect:

- this will increase weight ✓
- atmosphere is too thin and can't displace sufficient mass of gas per second **OR** blades can't spin **fast enough**✓
- can't get off ground due to insufficient lift force ✓

Do not accept increase in resistive forces or increase in drag for increase in weight.

***Must state that it is incorrect for all 3 marks**.*

Maximum of 2 marks for suggestions that more than doubles flight time.

Accept lift or thrust or upward force.

*A maximum of 1 mark for **MP3** and **MP1** where only mark seen is : idea that more energy is required.*

***MP2** can be scored independent of this.*

3

(e) Use of an appropriate equation of motion:

$v = u + at$ ✓

*By correct substitution including signs **or** correct rearrangement to make t subject.*

(t =) 0.15 (s) ✓

Accept answer correctly rounded to at least 2 sf.

Calculator display = 0.14784946236559

2

(f) Use of $v^2 = u^2 + 2as$

OR

Use of $v = u + at$ **and** $s = ut + \frac{1}{2}at^2$ **ECF**

OR

$mg\Delta h = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$ ✓

(h =) 0.61 (m) ✓ **ECF**

***MP1** (Downward journey)*

Allow s = 0.65m

$2.2^2 = 0^2 + 2 \times 3.72 \times s$

OR

*$2.2 = 0 + 3.72\,t$ **and** $s = 0 + \frac{1}{2}\,3.72\,t^2$* ***ECF***

OR

$m \times 3.72\,\Delta h = \frac{1}{2}\,m2.2^2$

MP1 (Upward journey)

Allow s=0.041 m obtained from

$s = 0.55 \times 0.15 - \frac{1}{2}\,3.72 \times 0.15^2$ ***ECF***

OR

$0^2 = 0.55^2 - 2 \times 3.72 \times s$

*Check possible **ECF** for t from (e) used in calculation.*

*Condone sign suppression in **MP1** where answer of 0.65 m or 0.041 m or 0.6(1) m is seen.*

Accept answer correctly rounded to at least 2 sf.

Calculator display = 0.60987903225806

2

(g) Student is correct:

Weight is the only force acting on the helicopter.

OR

Acceleration = (-)3.72 ms^{-2}✓

Due to **<u>Newton's 2nd law</u>**, the acceleration acts in the **same direction** as the weight (which is always downwards).

OR

Due to **<u>Newton's 2nd law</u>**, the acceleration is **constant** because the (mass and) weight are **constant** ✓

MP1 statement that the object is in freefall. Where (resultant) force is mentioned must be identified as weight.

Where acceleration is quoted must have correct unit.

Accept F=ma as a statement of Newton's 2nd law.

MP2 Accept no mention of force being weight where mass is included their answer, for e.g.:

*Due to **<u>Newton's 2nd law</u>** the acceleration is constant because the force **and** mass are constant.*

Neutral for statements that refer to deceleration / acceleration.

Do not accept arguments based on drag or air resistance affecting the motion of the helicopter.

***Zero marks** for statement that indicates the **acceleration varies**.*

*Must state that student is correct **or** that the acceleration is constant to gain 2 marks.*

2

[17]

Q6.

(a) Both t_m values correct: 0.404, 0.429

AND

Both t_m^2 values correct: 0.163, 0.184 ✓

Exact values required for the mark.

1

(b) Both plotted points to nearest mm ✓

Best line of fit to points ✓

The line should be a straight line with approximately an equal number of points on either side of the line.

2

(c) Large triangle drawn (at least 8 cm × 8 cm) ✓

Correct values read from graph ✓

Gradient value in range 0.190 to 0.222 ✓

Allow 2 or 3 sf for gradient

3

(d) g = 9.71 (ms^{-2}) or correct value from gradient value in **(c)** ✓.

(The answer must be in the range 9.0 to 10.5 (ms^{-2})).

Allow 2 or 3 sf.

Unit not required

1

(e) $$\% \ difference = \frac{(9.81 - 9.71)}{9.81} \times 100 \ = 1.02$$

OR correct computation using value from **(d)** ✓

If the candidate's value is exactly 9.81, then a statement that there is no (or zero) percentage difference is acceptable.

No sf penalty.

NB. Allow an answer from a calculation with either the candidate's value or the accepted value as the denominator in the equation.

1

(f) 0.001 s✓ (half the spread)

(Must have unit).

1

(g) $g = 2s/t_m^2$ ✓

= 2 × 0.300/0.245^2 ✓

= 10.0 (or 10.00) ms^{-2} ✓

Unit required and 3 or 4sf for the last mark.

3

(h) % uncertainty in s = 0.33 **and**
% uncertainty in t_m = 0.41 ✓

*Allow ecf from part **(f)**.*

% uncertainty in g
= 0.33 + (2 × 0.41) = 1.15 ✓

Allow ecf at each stage of calculation.

Uncertainty in g
= 10.0 × 1.15/100 = 0.12 m s^{-2} or 0.1 m s^{-2} ✓

*Allow ecf from part **(g)**.*

(allow 1 or 2 sf only)
(Must have unit for 3rd mark).

3

(i) (a) Use spherical objects of different mass **and** determine mass with balance ✓

Annotate the script with the appropriate letter at the point where the mark has been achieved.

(b) Would need **same diameter** spherical objects for fair comparison (same air resistance etc) ✓

(c) Time spherical object falling through same height **and** compare times

*Alternative for **(c)**:*
i.e. repeat whole of experiment, plot extracted values of g against mass. Horizontal line expected, concluding acceleration same for different masses.

3

[18]

Q7.

(a)

R / Ω	99.96	100.64	101.76	102.80	103.85	104.71
l / 10^{-2} m	2.500	2.508	2.523	2.536	2.548	2.557
l^2 / 10^{-4} m^2	6.250	6.290	6.366	6.432	6.492	6.538

correct values above **(1)(1)** (deduct one mark for each error)
(If two significant figures only – deduct one mark)

(2)

(b) both axes, with units, correctly labelled **(1)**
six points correctly plotted **(1)**
best straight line through plotted points **(1)**
sensible scale **(1)**

(4)

(c) at R = 103.40 Ω, l^2 = 6.46 **(1)** × 10^{-4} m^2 **(1)**
thus l = 2.542 × 10^{-2} **(1)** (m)
constantan resistivity = 47 × 10^{-8} (Ωm) **(1)**
= 1.2(1) × 10^{-5} m **(1)**

(5)

(d) tensile strain = $\frac{\text{extension}}{\text{original length}}$ **(1)**

(at R = 103.40 Ω, l = 2.542 × 10^{-2} m)

thus strain = $\frac{(2.542 - 2.5)}{2.5}$ **(1)** = 0.017 **(1)**

(max 2)

[13]

Q8.

planning

(a) sensible key factor e.g. p.d. across paper, that, when varied, leads to the determination of resistance: candidate then goes on to estimate the thickness of the paint layer on strip [only allow direct measurement of resistance if the investigation is of how either width or length of a rectangular strip affects the resistance of the paper] **(1)**

(b) correct measuring instrument given [allow circuit diagram] **(1)**

(c) dimensions of paper constant when resistance measured [to see how a certain dimension influences the resistance, width (if length varied)/length (if width varied)] **(1)**

(d) check that current through paper does not exceed 200 mA **(1)**

(e) sensible qualitative prediction given: thickness can only be estimated due to uncertainty in resistivity **(1)**

(f) thickness of layer (assuming uniform coating) in range 10^{-7} to 10^{-11} m **(1)**

[or (e) sensible qualitative prediction given: $R \propto l$ or $R \propto w^{-1}$]

(g) reasonable physics reasoning given in support: similarity with behaviour of a metallic conductor **(1)**

(h) use of V/I to find R [use of repeated readings to reduce uncertainty in measurement of dimension] **(1)**

(i) calculating possible range of thickness using limiting values of resistivity / assessing the uncertainty in result [plotting graph of results to check relationship] **(1)**

(j) any other sensible measure, e.g. maintain steady temperature **(1)**

[max 8]

Q9.

(a) $\sin\theta_1 = \frac{XZ}{WX}$ and $\sin\theta_2 = \frac{YZ}{WY}$ or $\frac{\sin\theta_1}{\sin\theta_2} = \frac{(XZ)\div(WX)}{(YZ)\div(WY)}$ 1 ✓

(must see this step either separately or in substitution for $\frac{\sin\theta_1}{\sin\theta_2}$ or 0/2

condone *i* and *r* for *θ* etc.)

$n = \frac{(XZ)\div(WX)}{(YZ)\div(WY)} = \frac{XZ}{WX}\times\frac{WY}{YZ}$ 2 ✓

$\left(= \frac{(XZ)\times(WY)}{(WX)\times(YZ)}\right)$

2

(b) idea implied that (XZ) × (WY) = *n* × (WX) × (YZ) is of form *y* = *mx* (+ *c*);

plot (XZ) × (WY) against (WX) × (YZ) [$\frac{XZ}{WX}$ against $\frac{YZ}{WY}$ etc] or 0/2 1 ✓

calculate gradient to find *n* (false plot loses both marks) 2 ✓

[must mention XZ, WX, YZ and WY for full credit: bland 'plot sin θ_1 against sin θ_2 and calculate gradient to find *n*'= 1 MAX]

[alternative method is to plot XZ against WX to find G_1 and plot YZ against

WY to find G_2 1 ✓; evaluate $\frac{G_1}{G_2}$ to find *n* 2✓]

2

(c) upper limit of (XZ) range [largest value] is suitable 1 ✓

largest XZ value ≈ length of block (114)

[largest WX value ≈ diagonal distance (131) across block / used

(approximately) largest value of XZ [WX] available]2✓

lower limit of (XZ or YZ) range [smallest value] is not suitable3✓

smallest YZ [XZ] values have large percentage uncertainty / are unreliable] 4✓
(reject idea these values are too close to zero)

smallest WX value ≈ width of block (65)5✓

[statement that range is suitable plus quantitative comment comparing length of block (114) with 98 (the range of XZ data) or covers more than 85% of available range] 12✓✓

equivalent statement regarding WX: compares available range (131 to 65 = 66) with

63 (the range of WX data) $_{12}$✓✓ = 2 MAX

statement that range is suitable plus simple qualitative comment relating range to the block, e.g. 'a large fraction / part of the available XZ [WX] range is covered' $_{12}$✓ = 1 MAX (bland 'range is large / wide' is not enough)]

MAX 3

[7]

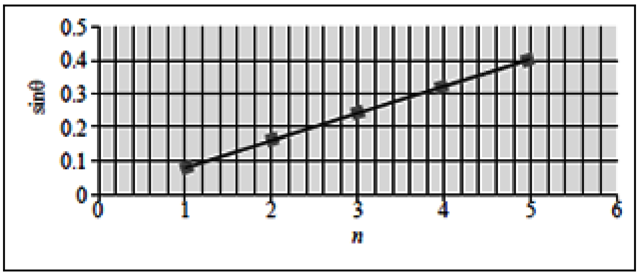
Q10.

(a)

	x / m	sin θ
1	0.173	0.086
2	0.316	0.156
3	0.499	0.242
4	0.687	0.325
5	0.860	0.395

1

If angles only calculated 1 / 2



at least 4 points plotted correctly **(1)**
best straight line **(1)**
gradient calculated from suitable triangle, 50% of each axis **(1)**
correct value from readings **(1)**
appropriate use of $d \sin\theta = n\lambda$ **(1)**
hence N (rulings per metre) = 1.25×10^5 m^{-1} (1.1 to 1.4 ok) **(1)**

max 2 / 6 if no graph and more than one data set used correctly, 1 / 6 only one set
if tan calc but plotted as sin, mark as scheme
tan or distance plotted, 0 / 6

max 6

(b) (i) maxima wider spaced [or pattern brighter] **(1)**
sin θ or θ increases with N [or light more concentrated] **(1)**

(ii) maxima spacing less **(1)**
sin θ or θ decreases with λ [or statement] **(1)**

(iii) maxima wider spaced [or pattern less bright] **(1)**
same θ but larger D [or light more spread out] **(1)**

6

(c) (i) waves in phase from **(1)**
any sensible ref to coherence **(1)**
whole number of wavelengths path difference **(1)**

(ii) use of geometry to show that sin θ = $\frac{\lambda}{d}$

max 3

[15]

Q11.

(a) (measuring 20T)

(idea of) reduces the **effect of** random error (on T)

OR

reduces the **percentage** uncertainty ✓

*allow (idea of) 'reducing **the effect** of uncertainty due to 'stop-start error' / 'human reactions' / 'human error';*

*accept 'to improve precision' / 'to reduce relative error' / reduces the **percentage** error;*

condone 'reduces the uncertainty in T '

'to calculate an average' is neutral;

to reduce 'uncertainty' / 'measurement error' / 'human error' / 'human reactions' / 'stop-start error' are neutral

'easier to measure' / 'improve accuracy' / comments about systematic error are neutral

1

(b) (repeating the (20T) measurements)

(idea of) a check for / enables the detection of / elimination of anomalies (in 20T) ✓

allow 'to avoid miscounting cycles';

accept 'to improve accuracy' / 'to reduce statistical error' / 'account for systematic error'

'to reduce the effect of anomalies' / 'to calculate an average' are neutral;

'to reduce (effect of) uncertainty' / 'measurement error' / 'human error' are neutral

'improve precision' / comments about random error are neutral

1

(c) average (20)T

OR

uncertainty in (20)T_1 ✓

for $_1$✓

average $20T$ = 19.2 (s)

(use evidence of calculator value 19.196 to confirm that all 5 sets were used)

OR

uncertainty in $20T$ = 0.27 OR $\frac{19.45 - 18.91}{2}$

allow 19.45 − 19.2(0) OR 19.2(0) − 18.91

average T = 0.96 (s) (calculator value 0.9598)

OR

uncertainty in T = 0.0135 / 0.014 (s)

OR $\frac{0.973 - 0.946}{2}$ *;*

allow 0.973 − 0.96 OR 0.96 − 0.946

percentage uncertainty **based on a correct method** = 1.4 % $_2$✓

for $_2$✓ accept any > 2 sf that rounds to 1.4%;

condone max 4 sf;

*do **not** allow 0.014*

2

(d) gradient evaluated from ΔT divided by ΔR_2 with $\Delta R_2 \geq 6$ kΩ;

OR

evidence of valid simultaneous equations with full substitution using read-offs for T and R_2 with $\Delta R_2 \geq 6$ kΩ $_1$✓

$_1$✓ is for the process, not the result

*allow **one** read off error;*

allow POT error in substituted data

expect gradient ≈ 5.5×10^{-5} (s Ω^{-1});

attempts to determine C by a valid method $_2$✓

award $_2$✓$_3$✓ for C in range with correct POT;

$_2$✓ is for the process, not the result

C in range 3.8×10^{-5} to 4.1×10^{-5} (F) $_3$✓

for $_3$✓ allow ECF for use of their R_1 ;

no ECF for POT OR a calculation error in gradient

attempts to determine R_1 by a valid method $_4$✓

award $_4$✓$_5$✓ for R_1 in range with correct POT;

$_4$✓ is for the process, not the result etc;

*do **not** allow working off grid to determine R_1*

R_1 in range 2.2 to 2.5×10^4 (Ω) $_5$✓

for $_5$✓ allow ECF for use of their C or their gradient

min 2 sf for ${}_3$✓ and ${}_5$✓;
allow ≥ 3 sf rounding to 2 sf in range;
don't penalise twice for results based on simultaneous equations with R_2 values in $k\Omega$

$$C = \frac{\text{their gradient}}{2 \times \ln 2}$$

OR

$$C = \frac{\text{their gradient}}{\ln 4}$$

OR

$$C = \frac{\text{their } \Delta T}{2 \times \ln 2 \times \text{their } \Delta R_2}$$

OR

correct manipulation of valid simultaneous equations

OR

$$C = \frac{\text{their } T}{\ln 2 \times (\text{their } R_1 + 2(\text{their } R_2))}$$

(where their R_1 has been found by a method not involving C; their T and their R_2 are corresponding values read-off **Figure 2**)

$$R_1 = \frac{2 \times \text{their vertical intercept}}{\text{their gradient}}$$

OR

$$R_1 = \frac{\text{their vertical intercept}}{\ln 2 \times \text{their } C}$$

OR

$$R_1 = \frac{\text{their } T}{\ln 2 \times \text{their } C} - 2 \times \text{their } R_2$$

*(where their T and their R_2 are corresponding values read-off **Figure 2**)*

OR

correct manipulation of valid simultaneous equations

OR

$$R_1 = \frac{T_P R_{2Q} - T_Q R_{2P}}{T_Q - T_P}$$

*(based on read-offs from **Figure 2** where their R_{2Q} is their value of R_2 at time T_Q etc)*

5

(e) marks can be awarded for suitable sketches

up to ${}_{12}$✓✓ for identifying that their R_2 should

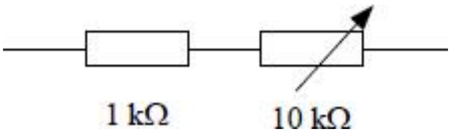
- have minimum resistance 1 $k\Omega$ ${}_A$✓

- have maximum resistance 11 kΩ $_B$✓
- be a (fixed) resistor (or resistors) **in series** with a variable resistor $_C$✓

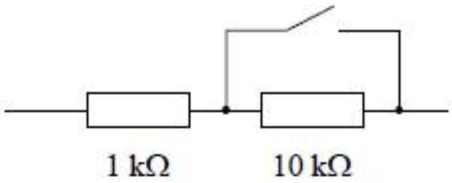
one 1 kΩ resistor **in series** with **one** 10 kΩ **variable** resistor

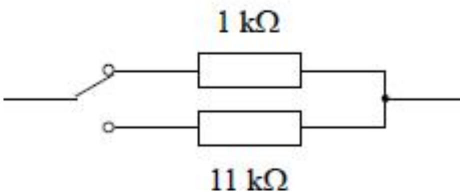
or valid labelled sketch $_3$✓

eg



allow $_A$✓$_B$✓ for a switched 2 fixed resistor circuit that can produce both limiting values, eg





allow $_A$✓$_B$✓ (R_2) from 1 kΩ to 11 kΩ;

allow $_{AB}$✓ for deducing range = 10 kΩ;

for $_C$✓ allow any arrangement that allows R_2 to be varied ***continuously*** *between limiting values;*

do not allow fixed resistor in parallel with a variable resistor

for $_3$✓ CAO

3

[12]

Q12.

(a) correctly deduces extension is 2.6 or 2.7 mm ✓

Should see $AC^2 = 1.50^2 + (6.34 \times 10^{-2})^2$;

(new) AC = 1.50134;

Extension of AC = (1.50134 − 1.50 =) 0.00134 m or 1.34 mm; and then doubles this

Final value must be to at least 2 sf

1

(b) evidence of correct working: ✓

$\sin\theta = \dfrac{6.34\times10^{-2}}{\text{their new AC}}$ or θ = 2.42° seen

OR

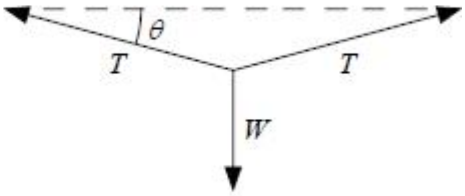
$W = 2T \sin \theta$ seen

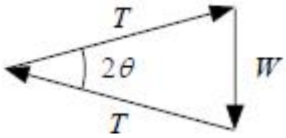
OR

suitable vector diagram with θ labelled

tension correctly calculated from $\frac{1.0}{2 \times \text{their} \sin\theta}$ ✓

For ₁✓ acceptable diagrams are shown below





Correct final answer of 11.8 N or 12 N earns both marks

2

(c) ruled best-fit line between first and sixth points;

line must pass above 2nd point

and

must pass below 4th point ₁✓

for ₁✓ withhold mark if line is thick, faint or discontinuous

gradient calculated from $\frac{\Delta(W/y)}{\Delta y^2}$ with $\Delta y^2 \geq 0.004$ ₂✓

(gradient ~ 3850)

for ₂✓ condone read off errors of ± 1 division

for ₃✓ note that $1.50^3 = 3.375$ so allow sub of 3.38

for ₄✓ reject 2 sf 1.2×10^{11}

evidence of using $E = \frac{\text{their gradient} \times 1.50^3}{1.11 \times 10^{-7}}$ ₃✓

for ₃✓ note that $1.50^3 = 3.375$ so allow sub of 3.38

E in range 1.10×10^{11} to 1.24×10^{11} (Pa) ₄✓

for ₄✓ reject 2 sf 1.2×10^{11}

4

(d) kg s^{-2} ✓

no credit for N m^{-1}

correct answer only

1

[8]

Q13.

(a) (i) diagram to show:

(long) wire fixed at one end **(1)**
mass / weight at other end **(1)**
measuring scale **(1)**
mark on wire, or means to measure extension **(1)**

max 3

[alternative for two vertical wires:
two wires fixed to rigid support **(1)**
mass / weight at end of one wire **(1)**
other wire kept taut **(1)**
spirit level and micrometer or sliding vernier scale **(1)**]

(ii) measurements:

length of the wire between clamp and mark **(1)**
diameter of the wire **(1)**
extension of the wire **(1)**
for a known mass **(1)**

max 3

(iii) length measured by metre rule **(1)**
diameter measured by micrometer **(1)**
at several positions and mean taken **(1)**
(known) mass added and extension measured
by noting movement of fixed mark against vernier scale
(or any suitable alternative) **(1)**
repeat readings for increasing (or decreasing) load **(1)**

max 5

(iv) graph of mass added / force against extension **(1)**

gradient gives $\frac{F}{e}$ or $\frac{m}{e}$ **(1)**

correct use of data in $E = \frac{Fl}{eA}$ where A is cross-sectional area **(1)**

[if no graph drawn, then mean of readings
and correct use of data to give 2_{max}) **(1)**

max 2
(13)

The Quality of Written Communication marks are awarded for the quality of answers to this question.

(b) (i) for steel (use of $E = \frac{Fl}{eA}$ gives) $e = \frac{FL}{EA}$ **(1)**

$e = \frac{125 \times 2}{2.0 \times 10^{11} \times 2.5 \times 10^{-7}}$ **(1)**

$= 5.0 \times 10^{-3}$ m **(1)**

(ii) extension for brass would be 10×10^{-3}(m) (or twice that of steel) **(1)**
end A is lower by 5 mm √ (allow C.E. from (i))

max 3

[16]

Q14.

(a) 0.879 (m ✓)

1

(b) correctly determines R_4 **OR** divides their incorrect R_4 by their part **(a)** $_1$ ✓

Correct answer gives 0.15(1) ($\Omega\ m^{-1}$).

$_1$ ✓ *Correct R_4 = 0.13(3) Ω*

$_{12}$ ✓ *Allow a correction to m if their part **(a)** is in mm*

$_2$ ✓ *Condone 3 sf answer*

2

(c) micrometer screw gauge

OR

<u>digital</u> (vernier) callipers $_1$✓

Treat references to zero error as neutral unless explicitly linked to reducing random error.

For $_1$ ✓ allow 'micrometer' or 'screw gauge' or travelling microscope.

Reject '(vernier) callipers'.

repeat readings at different points (along the wire)

OR

repeat readings in different directions / orientations

OR

repeat readings AND reject / discard anomalies $_2$✓

Accept "readings" for "measurements".

Repeat "experiment" is insufficient.

calculate average / mean (from repeated readings) $_3$✓

for $_3$✓ some mention of repeat (readings) owtte must be seen somewhere in body of answer

3

(d) use of $A = \frac{\pi d^2}{4}$ $_1$✓

ρ = their **(b)** × 1.1(3) × 10^{-7} (Ω m) $_2$ ✓

for $_1$✓ allow POT in d; either $A = \frac{\pi \times 0.38^2}{4}$ ***OR***

*$A = \pi \times 0.19^2$ **OR** A = 1.1(3) (× 10^{-7}) seen*

For $_2$ ✓ expected answer is 1.7 × 10^{-8} (Ω m)

If no other mark given, allow 1 mark for 6.8 × 10^{-8} ($\Omega\ m$)

2

(e) decrease R_1 / 2.2 MΩ by a factor of 30

OR

increase R_2 / 3.9 kΩ by a factor of 30

OR

increase R_3 / 75 Ω by a factor of 30 ✓

unless quantitative change identified, must give new resistance, eg

(new) R_1 is 73 kΩ

(new) R_2 is 120 kΩ

(new) R_3 is 2.3 kΩ

1

(f) 2.1 (mm) ✓

allow > 2 sf answer rounding to 2.1 (mm)

1

[10]

Q15.

(a) (i) $W = 2mg \cos\varphi$ $\therefore m = W/(2g \cos\varphi)$✓

The question says *<u>show that</u>, so the candidates must write down both steps.*

1

(ii) Well drawn straight line of best fit.✓

The line should follow the trend of the points with an even scatter of points on either side of the line.

1

(b) (i) Triangle drawn with smallest side at least 8 cm in length. ✓

Correct readings taken from the line for the triangle ✓

Gradient in the range 0.45 to 0.49 (0.445 to 0.494) quoted to 2 or 3 significant figures ✓

The size of the triangle can be identified from readings taken from the line.
The third mark is independent of the other two: error carried forward for incorrect readings (or for a poor line of best fit) which give a gradient out of range is not allowed.

3

(ii) Candidate's answer for gradient in (b)(i) correctly multiplied by g (expected answer 4.6)✓

N ✓

No s.f. penalty.
The second mark is for the unit and can be awarded if the numerical answer is incorrect.

2

(c) $\delta x\%$ = 0.2 and $\delta y\%$ = *0.5*✓

$\delta(x/y)\% = \delta x\% + \delta y\% = 0.2 + 0.5 = 0.7$ ✓

Use of $\delta(x/y.)^2\% = 2 \times \delta(x/y)(\%)$ ✓

Final answer is (±) 1.4 (%) which automatically gains all three marks

Otherwise

Accept only 1 s.f. for 1st and/or 2nd marks.

The third mark is for the method, not the final answer

3

(d) (i) Systematic errors in measurements are errors which show a pattern or a bias or a trend ✓

Some acceptable alternatives

- ***A systematic error** is one which deviates by a fixed amount from the true value of a measurement*
- *An error which has the same value in all readings*
- *A difference between the true value of a quantity and the indicated value caused by a fault in the measuring device*
- *Accept a good example of systematic error.*

1

(ii) y would be larger✓

because angle θ would be smaller

or

because friction would be opposing the increasing weight of m✓

2

[13]

Q16.

(a) reads off λ_p $_1$✓

for $_1$✓condone POT;

expect λ_p = 635 ± 2 (nm) /

635 ± 0.02 × 10^{-9} / 6.35 ± 0.02 × 10^{-7} (m)

*allow evidence of working on **Figure 1***

1

use of n × their $\lambda_p = d \sin\theta$ $_2$✓

for $_2$✓accept subject n with no / incomplete substitution, eg

$$N = \frac{\sin\theta}{n \times \lambda_p}$$

OR

subject d and <u>full</u> substitution, eg

$$d = \frac{5 \times \text{their } \lambda_p}{\sin 76.3} \; / \; 5.15 \times \text{their } \lambda_p$$ *5.15 × their λ_p*

OR

correct result d = 3.27 (× 10^{-6} (m));

allow ECF in λ_p including POT;

allow recognisable d / 2 sf intermediate result

3

$$N = \left(= \frac{1}{d} = \frac{1}{3.27 \times 10^{-6}} \right) = 3.06 \times 10^5 \ _3✓$$

for $_3$✓ accept ≥ 3 sf in range 3.05 to 3.07 × 10^5 OR

$N = \frac{0.194}{their\ \lambda p}$ *(allow ECF for λ_p out of range but not if due to POT)*

1

(b) identifies an appropriate physical characteristic that makes the measurement of the (5th) maximum more difficult ✓

take 'it' to be the 5th maximum / peak

(centre difficult to locate because)

(5th) 'maximum is wider' / 'peak less pronounced' / 'less defined' or wtte;

allow 'maximum more spread out' / 'less pronounced'

OR

maximum 'is fainter' / 'less bright' / 'intensity reduced';

reject 'not as clear'

OR

(cannot use edges to determine location of centre because)

'whole maximum (may be) not visible' / 'can't see edges'

OR

*(**L_R** produces a range of wavelengths so)*

4th and 5th / adjacent fringes may overlap

1

(c) extrapolation of linear region of the **L_R** characteristic $_1$✓

*for $_1$✓ reads off where a ruled extrapolation to the linear region of the **L_R** characteristic reaches the horizontal axis*

the line must be free from discontinuities; condone a ruled dashed line

condone tangent meeting curve at I ≥ 10 mA

V_A for **L_R** in range 1.91 to 1.93 (V) $_2$✓

for $_2$✓ > 3 sf acceptable if rounding to 3 sf

2

(d) any fully correct calculation of the Planck constant $_1$✓

for $_1$✓ allow 2 sf

use of c = 3(.00) × 10^8 AND e = 1.6(0) × 10^{-19}

AND EITHER

V_A from (c) AND λ_p in range 620 to 650 nm / ECF their λ_p from (a)

OR

V_A = 2.00 AND λ_p in range 550 to 580 nm;

calculates mean of two valid calculations of the Planck constant;

result in range 6.10 to 6.50 × 10^{-34} (J s) $_2$✓

for ${}_2$✓ Planck constant result rounding to correct 3 sf

(check very carefully working leading to data booklet value 6.63×10^{-34})

1

(e) V_F corresponding to I_F = 21 mA read from **L_R** graph in **Figure 3**;

use of V_F = 2.01 (V) leading to R = 195 (Ω) earns both marks

calculates R from $\dfrac{6.1 - \text{their } V_F}{21(.0 \times 10^{-3})}$ ${}_1$✓

*for ${}_1$✓ accept evidence of working on **Figure 3** condone 2 sf eg V_F = 2.0 (V)*

allow POT error for I_F

1

R = 195 (Ω) from $\dfrac{6.10 - 2.01}{21(.0) \times 10^{-3}} = 195$ ${}_2$✓ 195 ${}_2$✓

for ${}_2$✓ evidence to show use of V_F = 2.01 ± 0.01 (V) must be seen, ie allow

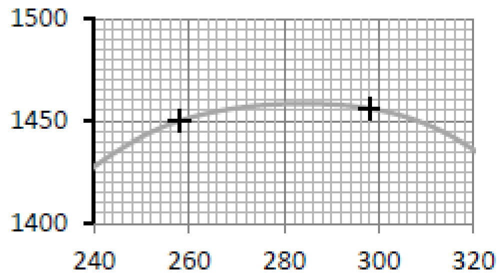
$\dfrac{6.10 - 2.00}{21(.0) \times 10^{-3}} = 195$ OR $\dfrac{6.10 - 2.02}{21(.0) \times 10^{-3}} = 194$

1

[10]

Q17.

(a) 2 missing points plotted, each to nearest 1 mm (half a grid square); points marked + or × or ⊙; reject thick points, blobs or uncircled dots ✓



1

(b) continuous smooth best fit line through all 7 points to 1 mm ✓

allow mis-plotted points to be treated as anomalies; multiple lines or points of inflexion lose the mark

1

(c) candidate's value from Figure 2 ± ½ grid square ✓

if multiple lines are drawn condone value if ± ½ grid square of all lines

1

(d) finding θ_N from Figure 3 is easy since the result is read off where G = 0 ${}_1$✓

or

finding θ_N from Figure 2 is difficult since θ has a range of values for which ε is a maximum ${}_2$✓

accept evidence that G = 0 used shown on Figure 3; physics error about how Figure 3 used means no credit for any further valid comment about Figure 2

accept 'curve is shallow at peak' for $_2$✓

MAX 1

(e) method:
correctly determines gradient of Figure 3 or uses gradient result with any point on line to determine (vertical) intercept $_1$✓

result in range 9.8 to 10.9 $_2$✓

gradient values in the range −0.040 to −0.034 for $_1$✓ (minus sign essential)

for $_1$✓ allow the substitution of at least one pair of correct values of G and θ into $G = \beta\theta + \alpha$ to obtain α using simultaneous equations

condone 2sf '10' for $_2$✓

2

(f) full scale pd = 100 × 1000 = 100000 or 10^5 μV ✓

allow 100 mV or 0.1 V if μV deleted from answer line ✓

1

(g) idea that resolution of the meter is not satisfactory $_1$✓
because the largest pd that will be measured is less than 1500 μV
OR
only uses 1.5% of the range
OR
pd across meter at full-scale deflection ÷ divisions = $\frac{10^5}{50}$ = 2000 μV per division $_2$✓

condone use of 'sensitivity' or 'precision' for 'resolution'; ignore 'meter is not accurate'

allow 'hard to tell different readings apart'

for $_2$✓ allow ce for incorrect 02.6

allow 'unable to measure to nearest <u>micro</u>volt'

allow 'resolution of scale should be 1 μV'

2

[9]

Examiner reports

Q1.

Although some very good work was evident, there was much evidence of carelessness in the answers seen. Common errors included the incorrect value for the lepton number of a positive muon in (a), a failure to identify the uncharged nature of the particles in parts (b) and (c), and giving incomplete answers. In part (d) in particular, many students only compared the rest masses of the particles and went no further.

Q2.

Most students achieved both marks on (a). Students who wrote '*a*' for the alpha particle did not receive credit. Several students also included other particles, such as neutrinos, in the equation.

(b) proved to be much more challenging. Most students were able to access the first mark, but few went on to explain fully why the boson was the W^-, often missing out any consideration of the significance of the charge.

(c) required students to set out the evidence clearly, linking it to the particular element being discussed. Although it was not penalised, many students discussed whether the lines of hydrogen or sodium matched those of helium, rather than the other way around.

Both (d) and (e) discriminated reasonably well, each producing a spread of marks.

The calculation in (d) was correctly completed by most students. In a significant number of wrong answers there was an attempt to calculate an energy difference which lost credit. Answers that were based on a difference in wavelengths were penalised further.

(e) proved to be more challenging. Answers were often vague or ambiguous. Important details related to the role of the photon, or the significance of energy levels, were also often missing. Rather than simply explaining emission, several students explained how the excitation happened in the first place, and this often led to confusion.

Q3.

(a) Nearly 50% of students achieved both marks. Those who gained only one mark often struggled to identify the correct velocity to use when multiplying by 1.7 s.

(b) The distribution of marks for this question was very uneven, with 35% getting full marks and an equal percentage achieving nothing. Competent students gained the answer succinctly using the equation $s = ut + \frac{1}{2}at^2$. Those students who were used to solving such problems by dividing the trajectory into two (either side of the maximum height) did not identify that the trajectory was not symmetric and struggled to give meaningful working.

(c) This question discriminated well. Shortcomings were often in the language used. For instance, "arrives faster" is not the same as "arrives sooner". (The ball actually arrives at the basket at the same speed regardless of the launch angle.)

(d) This was another challenging question. Again, imprecise language – e.g. "air resistance slows down the acceleration" – was frequently seen. Greater success was seen in answers that described the effects during decreasing, rather than increasing, vertical displacement. Some students misread the question and gave answers in terms of a_v increasing and decreasing.

Q4.

Approximately 80% of students gained this mark by showing sufficient working. A common error was to treat one of the values as an anomaly.

This question discriminated well. Many students gained 1 mark through using an incorrect number of cycles. The most common incorrect value seen was 2.5 cycles.

Success in this question was achieved by approximately half of the cohort. A final answer to two significant figures was condoned in this series, but only when processing showed some use of a value in millimetres.

Nearly 50% of students gained full credit for determining the acceleration using their values of displacement and time. By far the most successful route was to use $s = \frac{1}{2}at^2$. Students who calculated a speed using $v = \frac{s}{t}$ commonly failed to appreciate that this was the mean speed.

There was very low success for this question which was about the uncertainty in a measurement. Many students gave rote answers that did not address the context. References to rulers were common. The best responses explained why the resolution of the graph paper led to a 1 mm uncertainty in one reading and then stated that the measurement was based on two readings and therefore the two uncertainties needed to be added.

Students found this question surprisingly difficult with only about one-sixth of the cohort gaining both marks.

Students found this combination of theory and practice to be extremely challenging. Many suggested that the experiment had been performed in the absence of friction, rather than appreciating that the analysis ignored friction. By this logic, students argued that friction would reduce the acceleration and so the value of *g* would be smaller. A common misconception was that the value of *g* would be less than 9.81 m s^{-2} because the trolley was not falling vertically.

Q5.

(a) Students performed well in this part with 47% of students achieving all three marks. Those who made more limited progress were unfamiliar with how to determine the volume of air displaced each second and instead used $2\pi rh$ or $\frac{4}{3}\pi r^3$. Here again, realising that this is a “show that” question was crucial; students must ensure that their working clearly demonstrates *all* the steps they have made to produce the answer. Some students presented a one significant figure answer and this limited them to a maximum of two marks.

(b) This part of the question expected students to appreciate that the displacement of the gas produced an upwards force equal to the weight of the helicopter. This was beyond the knowledge and understanding of most. Fewer than 16% of students scored three marks and certainly demonstrated A-grade performance. Over 70% of students scored zero in this part. Many students thought that the mass of gas displaced per second was equal to the mass of the helicopter. Many attempted to use conservation of energy to obtain an answer by setting gravitational potential energy equal to kinetic energy. It was very common to see 0.4 × 3.72 as the only working presented.

(c) This part of the question was more accessible with almost 60% of students obtaining at least one mark. However, many students demonstrated a limited appreciation of the context and divided the energy stored in the battery by 39 s to find a power. This was incorrect as it assumed that all of the energy stored in the battery was transferred in 39 s. Many poorer performing students were unable to convert kilowatt-hours into joules.

(d) Almost 60% of students were able to score at least one mark. However, fewer than 10% of students were able to make further progress and not even 1% scored all three marks. Most realised that the helicopter was now heavier and that more work was required to keep it in the air. However, they were unable to describe how the helicopter produces the extra lift required. Also, they were unable to connect the increased amount of work done to power and therefore were unable to explain why the flight time would not double. Students would often make statements without being able to support them with an explanation that demonstrated their knowledge and understanding of the underlying physics.

(e) 58% of students obtained both marks. Almost 8% did not even attempt this calculation. Mistakes seen included dividing the acceleration by the change in velocity and using an inappropriate equation of motion.

(f) 11% of students did not attempt this calculation. 32% of students scored one mark, usually for determining the maximum height above the ground or the distance travelled upwards from the position shown in **Figure 3** to the maximum height. These students presented 0.65 m or 0.041 m as their answer without appreciating how this applied to this context.

(g) The lack of quality of the students' technical language was often the reason for limited progress in this part. Many thought that constant acceleration was the same as constant velocity and developed arguments based on acquisition of a terminal velocity. Many others offered Newton's third law as a reason to support equilibrium and Newton's first law.

Q6.

(a) Correctly answered by almost all candidates.

(b) As usual in this question a small proportion of candidates failed to accurately plot both points and an even greater proportion were unable to draw an acceptable line of best fit.

(c) Less marks were lost on this question than in previous years, most likely because these were mostly A2 candidates re-sitting the paper. Most candidates were able to calculate a gradient value within the allowed range.

(d) This was straightforward for nearly all candidates.

(e) A familiar question, well answered by most candidates.

Parts **(f)**, **(g)** and **(h)** discriminated well, with only the most able candidates scoring five marks or more.

(f) The easiest part of the question, requiring use of 'uncertainty = 0.5 × range'

(g) Although this was considered to be straightforward, many candidates failed to score the full three marks. Common errors were incorrect substitution into the formula and missing the unit in the final answer.

(h) This was the most discriminating part of the question, with candidates often scoring no marks. The process of adding percentage uncertainties to calculate the percentage uncertainty in the calculated value of g, and then converting back to an absolute uncertainty with suitable significant figures and unit was beyond most candidates.

(i) This proved to be difficult, and only the most able candidates scored more than one mark. An easy mark was often lost by lack of reference to measuring the mass of the spheres with a balance. Many candidates failed to realise that for a fair comparison the spherical objects would need to have the same diameter so that air resistance was the same.

Q9.

In part **(a)** most showed that $\sin\theta_1 = \dfrac{XZ}{WX}$ and $\sin\theta_2 = \dfrac{YZ}{WY}$ to earn a mark but some missed a key step in the manipulation that followed in arriving at $\dfrac{(XZ)\times(WY)}{(WX)\times(YZ)}$

In part **(b)** the majority saw we expected a simple application of the $y = mx + c$ idea and gained both marks.

Part **(c)** proved challenging for the candidates, most of whom made only limited progress by making an observation without any supporting explanation, e.g. by comparing the largest XZ value with the length of the block or by computing the diagonal distance across the face of the block and comparing this with the largest WX value. We wanted the candidates to discuss whether the limiting values of the data in the table showed if a suitable range had been used. Clearly the upper limit was ideal but the lower limit raised the question of whether such values could be measured without attracting a significant percentage uncertainty.

Better answers seen compared the range of the XZ data with the length of the block but we saw very few responses that earned full credit.

Several candidates used each row to calculate six values of refractive index and decided on the suitability of the data looking at the spread of results. Others judged the quality of the data based on the intervals between the values in each column. These approaches earned no credit.

Few could score more than 5 out of 7. A/B candidates scored between 3 and 5 while E/U candidates usually scored 1 or 2.

Q10.

This question attracted the smallest proportion of answers. For those candidates who attempted the question, the answers to part (a) fell mainly into one of two categories. In the first group were candidates who had obviously either seen or done the experiment or who at least were able to interpret the diagram correctly. This group of candidates could calculate the diffraction angles, plot an appropriate graph and use it to determine the final answer, scoring full marks. The second group consisted of those candidates who confused the situation with a Young double slit experiment. Although these candidates could plot a graph, there was no way that it could be related to any sensible means of determining the number of rulings per metre on a grating. It was impossible to award any marks to answers of this kind. There were some candidates who made some progress with the question but whose answers fell a long way short of the ideal. For example, some calculated the tangent of the diffraction angle but interpreted this as sine. Others did not plot a graph at all but calculated at least one value from the data. There was some merit in answers of this kind but, at best, they were worth one or two marks out of six.

Success with part (b) hinged upon the recognition of the relevance of the diffraction grating equation. Many, but not all, of those candidates who had interpreted the question as relating to the double slit experiment, continued with the same theme and few qualified for any marks. There was a minority of very good answers in which the grating equation was clearly stated and the effect of changing the appropriate variables was analysed. Some otherwise quite good answers were spoiled by imprecise use of language such as "more (or less) diffraction" or "the pattern becomes less". Some candidates thought that, in answer to part (b)(iii), the pattern remained unchanged because the diffraction angle did not alter.

Answers to part (c) were generally weak and many candidates left the answer space blank. It had been hoped that the diagram would provide a useful prompt, but this was not the case. Of those candidates who answered the question, many scored a mark for some reference to either "waves in phase" or "coherence". Few candidates were able to put together the logical steps stating the waves from each slit to have a whole number of wavelengths path difference, so being in phase and reinforcing when superposed. In answer to part (c)(iii), most candidates put n = 1 in the grating equation and did not use the diagram to show, for example, that a line drawn from D perpendicular to EQ has a length equal to the wavelength. The equation then follows naturally from this diagram.

Q11.

This question was about a variable frequency oscillator circuit.

The main ideas tested were

- ways to reduce or remove random and systematic error (3.1.2 and PS 2.3)
- calculation of percentage uncertainty from a set of tabulated data (3.1.2)
- understanding of the $y = mx + c$ idea (6.4 MS3.3)

In part (a) the preferred answer was that measuring $20T$ reduced the percentage uncertainty in T. We also accepted the idea that this reduced the effect of random error.

On (b) we expected the idea that repeating $20T$ enabled anomalous results to be identified. We do not accept the suggestion that measurements are repeated to mitigate the effect of anomalies. This implies that suspect readings should be included in the averaging process, but we want students to understand that anomalies, once detected, should be eliminated.

We assumed that students would make short work of part (c) but this was not the case. We saw quite a few invented solutions and some students did not use all the data in the table despite being told that all were valid. Some used 0.01 as the uncertainty rather than calculating half the range.

In (d) there were two approaches to how Figure 2 should be used. Most determined the gradient and intercept while a minority substituted values from two points on the line into simultaneous equations.

The most common error, and the principal reason why many scored 4 out of 5 marks, was using R_2 in kΩ in the gradient calculation, leading to a power of 10 error in their C. Another reason for 4-mark answers was the truncation of their C result to 4 × 10^{-5}.

Regardless of the type of error in C we allowed an error carried forward if this impacted the result for R_1. Inadequate presentation such as use of a similar looking 'C' for the unknown capacitance and for the vertical intercept undermined some efforts.

In part (e) most correctly identified that R_2 should vary from 1 k to 11 k but less than 20% could suggest a suitable circuit. Students often said they would *combine* a fixed and a variable resistor, but they needed to say these would be connected in series.

Q13.

Almost all candidates gained reasonable marks on part (a)(i) even though some of the descriptions were lacking in detail. Most of the diagrams were reasonably drawn with the aid of a ruler. Candidates who drew freehand usually produced inferior diagrams which failed to gain all the available marks. A variety of methods were shown, usually two wires hanging vertically, linked together by means of some vernier arrangement and a spirit level. Also shown was a horizontal wire on a bench. Although this is not such an accurate method, it was accepted but many candidates showed the mark on the wire as being about half way along. This of course is only acceptable if the length of the wire is measured to that point, but this was usually overlooked in the description. The least satisfactory method was suspending a single wire with a ruler alongside although this did gain some marks. There were an alarming number of diagrams which showed a completely unrelated length of wire, a ruler, an isolated hook with a mass attached and a micrometer. Needless to say, such efforts gained no marks.

In part (ii) candidates could have saved themselves considerable time and effort by reading the question carefully and just listing the measurement they would make. Many candidates listed the area of cross section as a measurement. This was not acceptable since area is a derived quantity and it is the diameter which is measured. Many candidates also listed the 'width' of the wire, which again was not accepted.

The descriptions in part (iii) were, on the whole, quite reasonable, although most effort seemed to go into describing how the length of the wire and its diameter were measured and not giving sufficient attention to the experiment, i.e. measuring the extension for each mass added and increasing the total mass to a certain value. There were very few references to repeating the readings while unloading. This particular section of the question was also used to award the quality of written communication marks and most candidates scored well on this.

The descriptions in part (iv) of how to use the measurements to give the Young modulus was reasonably done with about 50% of the candidates drawing a graph of force vs extension or stress vs strain and using the gradient accordingly. Candidates who only used one set of values to give one value of the Young modulus were not awarded all the available marks.

The calculation in part (b)(i) was performed satisfactorily, with the majority of candidates calculating the correct extension for the steel wire. Marks were lost in part (ii) when the answer was given without any reasoning.

Q14.

(a) Barely one-fifth of the cohort correctly determined the vernier scale reading. Some correctly determined the length but gave a final answer to 2 sf.

(b) This question tested knowledge of unit prefixes. About half the cohort correctly determined a value for R_4 and divided by their length from (a). A significant number of students successfully obtained a value for R_4 but did not go on to divide by their length. This had consequences for them in (d).

(c) This question was well answered by a majority of students. The second marking point was for the idea of repeating measurements along the wire or at different orientations. Statements such as "*repeat measurements at different locations*" were insufficient for credit. Comments about considering a zero error were treated as neutral unless they explicitly referred to a way of reducing random error.

(d) An allowance was made here for students who used their incorrect length and their incorrect R_4, but students who used their final answer to (b) as a value for R in the resistivity equation were penalised. Students should be aware that such "error carried forward" answers will be checked for correct rounding and are advised to use full calculator values or the values given in their working out.

(e) Barely 5% of students processed the information provided to make a correct deduction about changing one of the values of the fixed resistors. This question may be useful to teachers to illustrate the several steps of reasoning that are required to arrive at an answer.

(f) Similarly, this question shows how answers can be obtained quickly using proportionalities. Of the students who gained the correct answer, many explicitly worked out the value using the resistivity equation.

Q15.

(a) (i) Answered well by most candidates. The explanation had to demonstrate that candidates understood the resolving process.

(ii) Correctly answered by most candidates, with only a small proportion of inappropriate lines of best fit.

(b) (i) This question features on all ISA's but many candidates still fail to achieve the full 3 marks. The most common error was again misreading of one of the data points, and this then usually gives a gradient value out of tolerance, hence losing another mark. Triangles were generally large enough to meet the 8 cm criteria, with fewer lost marks on this point than in previous years.

(ii) Answered reasonably well by most candidates – by multiplying their gradient by 'g'.

A significant proportion of candidates lost the mark awarded for the unit. (Some candidates using 'n' instead of 'N' !).

(c) This question discriminated well, with only the most able candidates scoring all three marks. Significant figure errors and failing to double the combined uncertainty in x and y were the most common mistakes.

(d) (i) A surprising number of candidates failed to give an adequate description of a systematic error.

(ii) A large proportion of candidates scored the first mark, explaining that y would be larger. Only the most able candidates were able to give an adequate explanation, usually relating to friction opposing the increasing weight of m.

Q16.

This question was about the light emitted from different LEDs but included general ideas about the use of diffraction gratings, as used in Required Practical Activity 2.

In question (a) students had to make an easy read-off from Figure 3 and then apply an equation available in the *Formulae and Data booklet*. Despite the low demand of the question, fewer than a third of the students were able to obtain full credit.

Question (b) is one of several in the paper where those suggesting simple practically-based explanations were most likely to score. About 40% of students mentioned some relevant characteristic of the 5th maximum to score the available mark.

It was clear that some did not understand what we wanted them to do in question (c) and many showed no evidence of working on **Figure 4**.

In question (d) only 3% of the students successfully used data about both LEDs; some engineered an answer that duplicated the value in the *Formulae and Data booklet*. All students realised that *c* is the speed of light but not all recognised that *e* is the electronic charge and used 2.718 in their calculation.

Question (e) was the least accessible part and only 10% of students used **Figure 4** to determine the voltage drop across the LED before going on to deduce the minimum value of *R*.

Q17.

(a) Students should expect to be required to interpolate between grid lines when plotting points. Most students were able to do this satisfactorily, but errors reading the ε scale were surprisingly common. Another issue was associated with the style of point used. The standard has been long established in the legacy EMPA and ISA tests: thick points or blobs were not accepted.

(b) Thick, discontinuous, faint or straight lines forfeited this mark. Whilst some excellent lines were seen in answer to this question, some lines were thick enough to obscure the points. The line was expected to pass within half a grid square of all of the points. It was common to see careless drawing near the last point (392,1241), which lost the mark. Where it was clear that the points were incorrectly plotted far from the trend line it is surprising that students did not go back and check their answer to (a).

(c) An error was carried forward from their answer to (b) and most students were able to read the maximum correctly to half a grid square. However, it was common to see 1456 (the maximum in the table) even when the line on the graph did not support this value. 1335 was a common incorrect answer, suggesting that students were treating the ε axis as a number line.

(d) This question discriminated in favour of those who could write without ambiguity. Examiners were looking for an answer that explained that θ_n could be found from figure 3 simply by reading off where the value of G was zero (280 °C). Answers that discussed the difficulty of reading the value from figure 2 as there is a range of values for which ε is at, or close to, a maximum, also gained credit. Unfortunately many students implied that the gradient of figure 3 was easier to measure, or stated that finding where the gradient was zero was easier on figure 3 (seeming to suggest that there is such a point on figure 3). Some erroneously wrote about the relative difficulties of reading a point from a straight line rather than a curve. It was also relatively common to see comments referring to the different scale ranges in the two diagrams.

(e) Many very good answers to this question were seen, clearly demonstrating an understanding of the equation of a straight line and an ability to obtain data, such as the gradient, from a graph. An alternative acceptable approach was to use the values from two points and solve the two simultaneous equations produced. Many students incorrectly thought α was the value of G where the line touched the y-axis, and extrapolated the line back and extended the axis to find this point. Others mistakenly took α to be the gradient.

(f) Although many correct answers were seen, some suggested that several students were unfamiliar with the term “full scale deflection”, despite this being defined in the question. Others did not spot the μ on the answer line, writing down a value of 0.1 without changing the unit to match.

(g) There were many answers expressed so poorly that credit could not be given. Common examples were “the scale is too large”, “the divisions are not small enough” and “the scale does not have enough divisions”. Discussions related to accuracy gained no credit either. The best answers made it clear that the resolution of the meter was unsatisfactory, supporting this with a relevant calculation, such as the change in pd represented by one division (2000 μV). There was consideration made for answers based on an incorrect answer to (f). For example, those who had calculated the full-scale deflection to be 0., could gain credit for arguing that the range of the meter was inadequate. Several unsuccessfully argued that it was the susceptibility of the analogue meter to parallax error which made it unsuitable.